HIGHER SECONDARY
AND
INTERMEDIATE

PRACTICAL PHYSICS

(*For Indian, Bangla Desh and Pakistan Universities*)

Intended for Higher Secondary Schools, Intermediate and Degree Pass Courses

BY

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PREFACE

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Buddha Purnima.
3rd May, 1977.

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INTRODUCTION

1. Senses and Knowledge :—If a red ball is placed before a baby, he would stretch his little hand to get hold of the ball. It is because the baby likes the colour of the ball and tries to catch it. If it is given to him, very often he would try to put the ball into his mouth. This simple observation proves that from infancy we are apt to use our limbs to gain experience of the material world. These experiences are given to us by senses of touch, hearing, sight, smell and taste.

The happening of anything is called an event. The presentation of the ball to a child is an event. So long as we are little children the power of understanding remains in us in an undeveloped stage and such events do not rouse our inquisitiveness. We may like or dislike an event almost spontaneously. But as time goes on, our mind becomes more developed and we grow more and more curious about things and matters around us. As an illustration, a boy may casually notice that on a summer afternoon, the atmosphere becomes suddenly very stuffy, dark clouds appear in the sky and a storm follows almost immediately. In observing this event, it is very natural for the boy to put the question to his elders as to why a storm takes place. By observing a solar eclipse, he might very likely be led to think what wonderful an eclipse is and why it takes place.

With further growing of age, when we go to school and learn to read and write, our mind is then capable of a better reasoning and understanding. At this age, an event happening before the eyes might make us think about its nature of occurrence. The mind then tries to analyse the nature and cause of the event and in doing so our stock of knowledge increases. We become gradually familiar with a few modern machines. Railway locomotives, motor cars, steam vessels, electric tram cars, radio and electric amplifiers and various other objects attract our attention. This is just the time when the mind is set to work for analysis. At this stage we may not be satisfied with a mere description but we might even be tempted to see for ourselves the details of the working of the machinery. Thus, a tendency to study a machine and its mode of operation grows in us. The mind is then set ready to accept some systematic knowledge of an event.

2. Aim of Experiments in Sciences :—It is an observed fact that every natural or man-made event has a cause behind it and similar conditions put together always produce an identical result. It can, therefore, be inferred that the occurrence of an event is guided always by a definite law of nature. A systematic study of an event gives us a knowledge regarding the laws of nature working behind it. For example, water on being heated sufficiently always boils; or when a body is raised to a height and then released, it falls down to the ground. These are natural events. To study any one of these we have to observe under what conditions a similar

thing occurs. **The act of combining together a number of conditions with a view to verify an observed fact, is called an experiment.** To study the boiling of water, the act of putting water in a vessel and then heating it is an illustration of an experiment. Every experiment should be studied intimately from the beginning till the result is obtained. **A study of an experiment and the collection of data taken during the expriment is called an observation.** An intimate observation gives us information about the successive stages of an experiment. When observation is finished, we arrive at a result of the experiment. **A logical interpretation of the result is called an inference.** Therefore, every experiment is closely associated with an observation and is followed by an inference. A student of science while making an experiment should never be guided by any bias or prejudice. Suppose that he is required to measure the length of a rod. In his first attempt he finds the length to be exactly 8 inches. He should always keep it in mind that the length, he has obtained, depends upon the placing of the scale and the manner of taking the readings. He should start with an open mind that the length of the rod under observation might be 8 inches or slightly greater or slightly less than 8 inches. Every precaution must be taken to record very accurate readings eliminating all possible sources of errors. In every experiment we get a few correlated conditions and a result. Thus, the object of an experiment is to correlate a few conditions producing an event and thereby to analyse by a result the law of nature guiding that event.

3. **Nature of Experiments** :—We can devise some experiments for popular demonstrations as well as for laboratory study. In the former case we may only show the conditions or factors producing an event. Thus, by heating water to the boiling point, we demonstrate that water boils on being heated. The purpose of a laboratory experiment is to have a deeper insight into the matter for which we have to make experiments with finer apparatus and determine each factor in exact proportion. Thus if we weigh a quantity of water in a balance and note its initial temperature with a thermometer, then on raising the liquid to the boiling point and determining its final temperature we can exactly calculate how much heat would have been necessary to raise the given amount of water to its boiling point. Here we get a quantitative relation between the amount of heat, the amount of water and the range of temperature in the particular experiment. Therefore a physical law is most intimately known when we can express it with all the quantities involved in exact proportion and this is only possible by careful and accurate experiments.

4. **Essentials of Experimentation** :—It has already been stated that the aim of an experiment is to find or verify some physical laws governing an event. **A precise interpretation of the principle to be established by an experiment is called the theory of the experiment.** Therefore, once the theory of an experiment is known,

we are in a position to select the type of the experiment to carry on. Ordinary laboratory experiments are designed for the verification of certain laws already discovered by original workers.

Before commencing any experiment a beginner should be thoroughly conversant with its theory; that is, he must know what he is going to verify or establish. Experimentation has no meaning unless the worker has got some definite object in view. A student possesses a justification of doing an experiment only when he has grasped the theory well.

To put a theory to an experimental test, suitable apparatus are required. In order to be able to handle the apparatus in a proper way, the worker must have to know the purpose of each of the apparatus required for the experiment and its mode of operation. Ignorance or carelessness in handling an apparatus might damage the apparatus, resulting in a complete failure of the experiment.

After the apparatus have been fitted up, the experiment is started and observations are recorded systematically in a note book. A candidate desiring to perform a successful experiment must be all attentive and vigilant while making observations and recording them. Because some effects during observation might be momentary and a few others too faint to escape a careless eye.

When observation is finished and readings are collected, necessary calculations are made to arrive at the result. Sometimes a graph is to be drawn to show the relation between two varying quantities. Thus, we derive a conclusion from the result of the experiment. The calculated result on being compared with the standard result shows a slight or large variation in proportion to the degree of accuracy attained during observation. The following are the principal sources of errors in an experiment with the methods of eliminating or minimising them.

5. **Errors of Observation** :—In carrying out an experiment we have to record some observations as indicated by the apparatus used in connection with the experiment. In recording such observations we always make their estimates by our senses such as eyes, ears, fingers etc. The response to these senses varies slightly from a person to a person and it is never perfect So every measurement, however carefully made, is liable to some inaccuracy depending upon errors of observation. Of these some can be eliminated because they arise from causes which can be controlled by the worker with his experience and skill. For example, it is well-known that a very hot body placed in air produces around it streams of air moving upwards, which is usually known as convection current. A convection current of air would naturally disturb the equilibrium of the pans of a physical balance. An attempt to weigh a hot body in air will not therefore give a correct weight. The error can be avoided by allowing the body to cool before weighing. Some apparatus are to be levelled before use and some screws are to be turned in one direction to avoid certain

errors in measurements. Such types of errors would be dealt with in proper places of the book.

A few other sources of errors cannot altogether be avoided but can be minimised to a great extent. As already stated, our estimation in any measurement is accurate upto a certain limit beyond which any attempt at a greater accuracy is untrustworthy. For example, in measuring the length of a rod with a millimetre scale, one can possibly measure with eye-estimation its length correct to half or quarter of a millimetre. If its true length be, say, 20·365 millimetres and if a number of measurements be taken, some of the readings might probably be very nearly 20·5 mm., *i.e.*, a little higher than the true value and a few others might be about 20·25 mm., *i.e.*, a little less. If a good number of readings be taken they would be such that their *arithmetic* mean is very nearly equal to the actual length. The larger is the number of readings taken, the nearer is their mean to the true value or the **most probable value.**

A third source of errors may be due to the imperfections of the apparatus supplied. The error is then systematic and can only be detected either by comparing the apparatus directly with a standard apparatus or by observing a systematic discrepancy of the result arrived at with the standard result. By observing a discrepancy in the result, we should not abruptly conclude that the apparatus supplied is wrong. Such a decisive conclusion might follow when all other sources of errors are minimised or eliminated completely.

6. Influence of Errors on the Experimental Results :— In almost all experiments the final results are found by calculation from a number of quantities directly observed during experiment. It is evident then that any error committed in recording one or more quantities would creep into the calculation and would affect the final result. Let us suppose that the most accurate result of an experiment is X. But due to some errors, we have found a value X_1. Then $X_1 - X$ is the error for a value of X. Thus the error for unit value is $(X_1 - X)/X$. The amount of error, assuming the standard result to be 100, is called the percentage of error. This will evidently to $100\,(X_1 - X)/X$ in the above illustration. The percentage of error is positive or negative according as X_1 is greater or less than X.

Measurement of larger quantities with equal skill generally involves a smaller percentage of error. For example, suppose that in measuring the length of a rod of length 50 cm., a person makes an error of a 0·1 cm. in reading the length. The percentage of error* is then $\frac{\cdot 1 \times 100}{50} = 0{\cdot}2\%$. If in reading a length of 10 cm. he makes an equal error of 0·1 cm. the percentage of error becomes $\frac{\cdot 1 \times 100}{10} = 1\%$. Thus, for an equal amount of error, the larger is the quantity to be measured the smaller is the percentage of error. Thus, to ensure accuracy in

*When a large number of readings is taken for any measurement, the most probable error and the mean error may be found by calculation from the theory of probabilities. As this is usually done in standard experiments and in research works, it is outside the scope of this book. A mechanical process of calculating these errors is however embodied in the Appendix 1 at the end of this Book.

results, smaller quantities should be measured with a greater precision than larger quantities. One hundred minus the percentage error is called the percentage accuracy. Thus an error of 5% is equal to an accuracy of 95%.

Experiments often involve measurements of small lengths, small masses and short periods of time. For this reason we require very sensitive apparatus capable of measuring lengths accurate upto one hundredth part or even one thousandth part of a centimetre. This is attained practically by means of a vernier scale, a micrometer screw-gauze or a spherometer. Delicate balances can be used to weigh a body accurately upto a thousandth part of a gram. Time can be measured with a precision stop-watch upto one-six-hundredth part of a minute. The percentage accuracy in measurements can be pushed higher with apparatus of higher precision.

7. Relative Accuracies of Readings and Calculated Results :— Every experiment involves the recording of a few readings and the apparatus used in each experiment provide facilities of some order of accuracy with which these readings can be taken. For example, in measuring the density of a solid, we have to find its volume and mass. Suppose that we are supplied with a graduated cylinder having graduation of 0·5 c.c. and a physical balance with a weight-box having ·01 gm. as the minimum weight.

The worker at this stage ought to know the relative accuracy with which the measurements of volume and mass are to be taken. Suppose that by applying the displacement of water method, the volume of the body is found to be 10·5 c.c. It is quite probable that however accurately he might have measured the volume with a 0·5 c.c. graduated cylinder, there might be an error of $\pm 0 \cdot 25$ c.c. or so in reading the given volume. Hence the percentage error in volume determination is 2·5% or a percentage accuracy of 97·5%. It is *of no use then to measure the mass of the the body with an accuracy greater than* 97·5% *in this particular experiment.* Further suppose that a rough determination of the mass of the body gives nearly 27 gm. To secure the required percentage of accuracy the body need not be weighed more accurately than 0·5 gm. which nearly equals an error of $\pm 2 \cdot 5\%$ So measurement of mass of the body to the nearest decigramme is quite sufficient for this experiment. Let the measured mass of the body be 27·6 gm.

Thus, the mass of the body of 27·6 gm., and its volume of 10·5 c.c. being measured, the density is now to be calculated. Since both are expressed to three arithmetical figures, the value of density should also be expressed to three significant figures ; that is, its value is 2·63 gm. per c.c. Here the accuracy of the final result is also about 97·5% and with such an order of accuracy any digit in third place of decimals cannot be truly ascertained. The idea of relative accuracy in reading various quantities in an experiment would be more and more clear with experience in measurements.

8. Conduct within Laboratory ;—It will not be out of place to mention certain general conduct which should be maintained by

every worker in the laboratory. A student in the Practical Class should always behave in the Laboratory in such a manner as to offer maximum facility to all other workers. To secure this object *silent work is essential.* The stock of a laboratory is limited and so it cannot possibly maintain more than one or two pieces of each apparatus and, therefore, a certain round of experiments is fixed up by teachers in the laboratory for a particular batch of students, so that each worker gets an opportunity of doing an experiment in its proper turn. Each student should utilise his or her turn in the best possible way as otherwise the systematic cycle of work is sure to be dislocated. A few other instructions are also given herewith for a smooth running of the Practical work.

(*i*) Report any breakage or loss of the apparatus immediately to the Head of the Laboratory so that the apparatus may be replaced or repaired for the next batch. (*ii*) Do not allow water, salt solution mercury or acid to come in contact with the metal parts of the apparatus; apparatus so soiled should be wiped clean with a piece of cloth, dried and smeared with vaseline. (*iii*) Do not dismantle any apparatus unless required to do so. (*iv*) Do not scratch or disfigure benches, working tables, etc. (*v*) Do not throw water or acid on the floor, but do it into sinks or basins. (*vi*) Do not meddle with electric switches and taps. (*vii*) Do not take your seat on the working tables. (*viii*) Do not short-circuit the poles of the cells and batteries.

9. General Instructions for Laboratory Works:—It is needless to say more than once that before attempting to do any experiment in the laboratory a student must thoroughly be conversant with the theory of the experiment, the method of procedure and recording of observations. Observations should be tabulated under various columns. A tabulated chart always facilitates a comparative study of the collected data.

A student must have *two* Practical Note Books. Of these, the one called the Rough Practical Note Book is an ordinary Exercise Book and is meant for recording observations in the laboratory during the course of experiment. After the recording is finished the necessary calculations are made on the same book to get the result. Since the success of an experiment depends primarily on the accuracy of the result arrived at, it is always advisable to calculate the result of an experiment before taking up the next. The other note book, called the Fair Note Book, has got a standard size and is meant for a neat entry of the experiments with fuller details. Each leaf of this book is blank on one side and ruled on the other, with some marginal space. The Fair Note Book is kept at home and is presented from time to time to the Laboratory for inspection and signature of the Teacher in charge. It should be the motto of a student to write out the experiment in this book as soon as possible after he has done it successfully in the laboratory.

10. Recording of Experiments:—In the Rough Practical Note Book, which is meant for recording observations in the

laboratory, write the **Date** on which a particular experiment is performed at the top of the page. Below this, enter the **Number and Name** of the experiment. Then under the heading **Theory,** state only *the working formula with an explanation of the various quantities* or symbols *occurring therein.* The deduction of the formula and other details are not necessary. As the Sub-headings stated above bear no direct connection with the experimental procedure, you can conveniently enter them into the Rough Note Book while making theoretical preparation for the experiment before coming to the laboratory.

Under the heading **Result**, post each reading during the progress of the experiment **in a tabulated chart**. Readings should generally be expressed in terms of decimal fraction with proper units. For any measurement take a number of readings (usually three to five) and find their mean value, which represents the reading for that observation. After finishing the experiment, calculate the result *in its proper unit* and compare it with the standard result. Draw the **graph**, wherever necessary, on a squared paper. Before taking up another experiment show your data and calculated result to the Teacher in charge for his inspection and remarks. Other things being in order, if your observed result is acceptable within the limits of experimental error you would get a change over to the next experiment. Avoid use of loose sheets of paper for recording observations or use of erasers to obliterate any inaccurate reading. Strike out with a scratch any inaccurate or improbable reading which might have been recorded. Such a reading when examined later on gives an idea of the amount of variation from the probable set of readings.

The recording of an experiment in the Fair Note Book should be in greater details as enumerated below :

II. Date and Heading of the Experiment :—The date on which the experiment is done is to be put down within the marginal space at the top. The name of the experiment should be written in block types.

Theory—The theory should be short including a statement of the mathematical formula used. The different symbols in the formula should be explained but its proof may not be necessary.

Apparatus—A list of the apparatus used, together with a brief description of each, may be given. A sectional diagram showing the arrangement of the apparatus should be drawn on the left-side blank page and its various parts should be lettered for reference in description.

***Method of Procedure**—A systematic account of the manner

*A statement of the method of procedure, made by a student in the Fair Note Book, should better be *worded in the passive voice*. Although it is a record of his own work, the statements "I did it, I observed it etc." do not hear so well as "It was done ; it was observed etc."

The method of procedure of each experiment in this book is a direction given by a teacher to a student. So the sentences are in active voice. It is hoped that the students would turn such sentences into passive voice and enter them in the Fair Note Book.

in which the experiment is carried out should be given together with the various precautions taken to avoid or minimise sources of errors of observations.

Experimental Results—Readings should be recorded in tabular forms with corresponding units* Even individual reading should be recorded and the mean value should be shown in a separate column. It is advisable to use the Logarithmic Table in making calculations and to show such calculations on the left-side page. Results with proper units should be expressed in decimals upto a few places according to the order of accuracy attained in the experiment. Graphs should be drawn wherever needed.

Discussions—This should include a discussion of the various of errors which might have crept in during experimental observations and of the percentage of error of the result arrived at. Any incidental inaccuracy or any defect with the apparatus supplied should also be stated, if found.

CHAPTER I

FUNDAMENTAL MEASUREMENTS

1,1. Units of Measurements :—Units are broadly divided into two kinds,—Fundamental and Derived. A *fundamental unit* is one which stands by itself and is not dependent on any other thing. A *derived unit*, on the other hand owes its existence on fundamental units. The fundamental units are **units of length, mass and time.** In measuring each of the fundamental units some definite and convenient quantity of the same kind is chosen as the standard in terms of which the quantity as a whole is estimated. This is called the *unit* for that particular quantity. There are broadly *two* systems of units ; the Metric or **C. G. S.** (centimetre, gramme, second) units and the British or **F. P. S.** (foot, pound, second) units.†

Units of Length—The standard unit of length on the C. G. S. system is called the **metre.** The length of a metre has been internationally accepted as the distance between the ends of a certain rod of platinum-iridium which is preserved at the Archives de Paris at a temperature of 0°C. Once this length is accepted as a metre, the unit becomes fixed all over the world.** Laboratory metre scales are compared with such a standard metre or a substandard before

* Tabular forms wherever possible have been embodied in the book.

† Before starting to read this article, a student should better consult a standard Textbook regarding Units and Measurement. For reference *vide* Basu & Chatterjee's Intermediate Physics, Vol. I, General Physics Arts. 4, 5 & 6.

**In a Science Convention held in 1960, a Metre has been redefined by International Agreement as 1,650, 763·73 wavelengths of orange-red spectrum line of the element krypton.

graduation. For measuring small distances or lengths, sub-multiples of a metre are used as given in the following table.

1 metre (m) = 10 decimetres (dm.)
1 decimetre = 10 centimetres (cm.)
1 centimetre = 10 millimetres (mm.)

Thus 1 metre = 100 centimetres = 1000 millimetres.

Very large distances are measured in terms of a kilometre (km) which is equal to 1000 metres.

The standard unit of length on the F. P. S system is the British Imperial Yard which is defined as the straight distance between the centres of two transverse lines on two gold plugs on a bronze bar at a temperature of 62°F preserved at the Office of the Exchequer, London. Submultiples of a yard are the following:

1 yard = 3 feet (ft.); 1 foot = 12 inches (in.)

Thus 1 yard = 36 inches.

Large distances are measured in terms of a mile which is equal to 1760 yards.

The C. G. S. system of measurement is more popular because of its simplicity of conversion from one form into another. For example, 3538 mm = 353·8 cm. = 3·538 m. But on the F. P. S. system, we have to divide or multiply one quantity by an arbitrary number to convert it into another unit. The relation between two systems of units is given below:

1 metre = 39·37 inches and 1 inch = 2·54 cm.

1 2. **Measurement of Length** :—For practical purposes we have to measure distances ranging from several million miles to a small fraction of a millimetre. The same instrument can not conveniently be used for measuring all distances. Different instruments and methods are, therefore, used for the measurement of length, each one suited to a particular range of length.

Trigonometrical Survey :—Very large distances covering thousands of miles, the direct measurement of which is either impracticable or impossible, are determined by a process called the Trigonometrical Survey. Suppose that P is a point object placed at a large distance from a plane surface ABC (fig. 1). It is possible to know the distance of P from any point of the surface. Take any two points A and B on this surface. A and B are called observation stations and the straight line joining the two stations is called the *base line*. At first the length of this base line is measured *accurately* by any suitable process. Let the length AB of the base line be l. Then, from the station A, the point P is observed and the angle BAP ($=\alpha$, say) is determined with a suitable apparatus such as a sextant (vide measurement of angle). Similarly, from the other station B, the angle

Fig. 1

ABP ($=\beta$ say) is measured.* Thus knowing l, α and β we can find the length AP or BP or even the perpendicular distance PC from the principles of Trigonometry in the following way. In the ΔPAB, the $\angle APB = 180^\circ - (\alpha + \beta^\circ)$. Again, in the ΔPAB,

$$\frac{AP}{\sin\beta} = \frac{BP}{\sin\alpha} = \frac{AB}{\sin[180^\circ - (\alpha+\beta)]} = \frac{AB}{\sin(\alpha+\beta)}$$

$$\therefore \quad AP = l\,\frac{\sin\beta}{\sin(\alpha+\beta)} \text{ also } BP = l\,\frac{\sin\alpha}{\sin(\alpha+\beta)}$$

$$\text{Again, } PC = AP \sin\alpha = l\,\frac{\sin\alpha\sin\beta}{\sin(\alpha+\beta)}$$

Thus the distance of the object P from any one of the observation stations or the perpendicular distance of P from the base line can be determined.

Large distances on earth are mostly measured with this process. The length of a mountain range or the boundary line of a country is determined with the survey method. As stated already, every measurement, however carefully made, involves some error. Measurement of angles and base line entails small errors not exceeding a foot in a mile or half a minute in a right angle. Hence the percentage of error in finding the distance of P is not more than 0·02% which is considered to be a high degree of accuracy in practical determinations.

Example :

From two base stations having a distance of 1000 yards, the angles of inclination of a hill top with the base line in a vertical plane are found to be 42° 26′ and 27° 12′ respectively. Determine the distance of the hill top from the base stations, as also the height of the hill.

A. Let A and B be two stations and P, the position of the hill top, the plane containing the points A, B and P being vertical. Then, according to the problem AB = 1000 yd., $\alpha = 27^\circ\ 12'$ and $\beta = 42^\circ\ 26'$.

$$\text{Then, } AP = 1000\,\frac{\sin 42^\circ\ 26'}{\sin(27^\circ\ 12' + 42^\circ\ 26')} = 1000\,\frac{\sin 42^\circ\ 26'}{\sin 69^\circ\ 38'}$$

Referring to the natural sine table at the end of this Book.
$\sin 42^\circ\ 26' = {\cdot}6747$ and $\sin 69^\circ\ 38' = {\cdot}9375$

$$\therefore \quad AP = 1000 \times \frac{{\cdot}6747}{{\cdot}9375} = 719{\cdot}7 \text{ yd.}$$

In a similar way,

$$BP = 1000\,\frac{\sin 27^\circ\ 12'}{\sin 69^\circ\ 38'} = 1000 \times \frac{{\cdot}4751}{{\cdot}9375} = 487{\cdot}6 \text{ yd.}$$

$$\text{Also } PC = \text{height of the hill} = 1000 \times \frac{{\cdot}4571 \times {\cdot}6747}{{\cdot}9375} \text{ yd.}$$

$$= 328{\cdot}9 \text{ yd.}$$

Measuring Chain and Tape :—Distances from a few hundred yards to a few yards are measured *directly* with a chain or a tape. A chain is usually 66 ft. or 100 ft. in length consisting of inter-connected pieces of steel rods, each one foot long and subdivided into inches (Fig. *2a*). To use a chain for measure-

*If the object P is a moving object, such as an aeroplane or a planet, measurements from A and B are to be taken simultaneously by two observers.

ment from a certain point, firmly fix a pin P (Fig. 2b) on the ground vertically and slide an end link T of the chain over the pin. Fully stretch the chain in the direction of measurement, care being taken that the chain does not show kink or sag anywhere. Put a mark where the other end link terminates and fix another pin there. This gives the length of one chain. Next with the second pin as the point measure another chain along the same direction and put another pin at its terminus. In this way the entire distance is measured in terms of the number of chains. The last part of measurement is done by counting the number of foot links of the chain. If a careful measurement is made the error does not exceed more than a foot in a mile. Hence the percentage of error is $\pm\frac{1\times 100}{1760\times 3} = \pm$ ·02%.

A measuring tape is sometimes graduated on its one side in

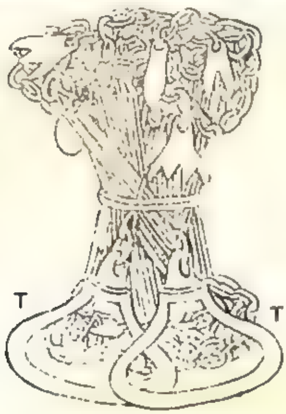


Fig. 2a—Chain

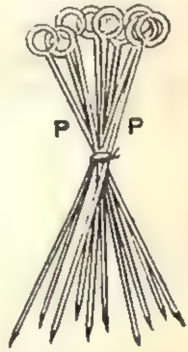


Fig. 2b—Fixing Pins

inches and on other side in centimetres (Fig. 3). It is usually a lace or a steel tape on which the graduations are printed. The tape is wound upon a frame which can be rotated with a handle. The tape is protected within a covered casing B and can be pulled out whenever necessary. Steel tapes of smaller lengths coiled in casings are prevalent nowadays. The method of measurement with a tape is similar to that of a chain. When measured carefully there is probably an error of not more than one or two inches for every 100 yards. This gives a percentage of error not exceeding 0·06%, which is sufficiently accurate for practical purposes.

Fig. 3—Measuring Tape

Metre Scale or Metre Stick :—Lengths from a few feet to a few inches or centimetres are measured with a metre scale (Fig. 4). The measuring scale, which is made of box-wood or of some metal has got its one edge graduated in centimetres and the other in inches. The top side numbering of Fig. 4 is in inches and the

lower side in centimetres. The smallest division on the centimetre side is a millimetre (0·1 cm.) and that on the inch side is 0·1

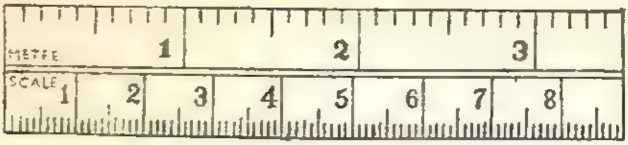


Fig. 4—Metre Scale

inch. In measuring length with a metre scale, sometimes the scale is used directly and sometimes in conjunction with some auxiliary apparatus as the situation demands.

Direct Application of the Scale—In order to use a metre scale following instructions should be followed :—Place the scale alongside the body, whose length is to be measured. You need not make one end of the body touch the zero of the scale or even the end of the scale. In either of the cases there may be an error called the 'end effect' which we shall discuss presently. Now take the readings of the scale corresponding to the two extremities of the object.

If x be the scale reading corresponding to one end of the object and y that of the other end, then the length of the object is $x \sim y$. Thus, if one end of a rod be coincident with 10 cm. of the scale and its other end be found against 46·6 cm., then the length of the rod is 46·6 − 10 = 36·6 cm.

Eye-estimation—When the extremity of an object does not coincide with any graduation of the scale, the following method is to adopted. Suppose that you have placed a rod AB alongside an inch

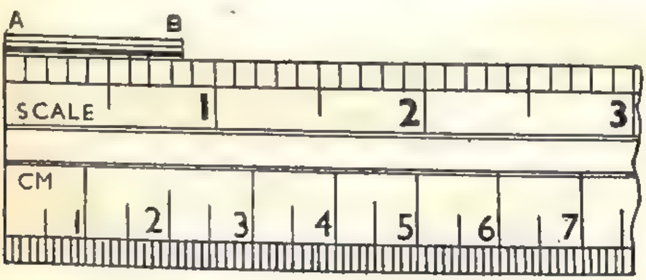


Fig. 5—Process of Eye-estimation

scale, with one end A of the rod coinciding with the zero of the scale (Fig. 5). The other end B of the rod is found to lie between 8th and 9th divisions. Since each division of the scale is 0·1 inch, the length of the rod is 0·8 inch *plus some fractional part* of 0·1 inch. Now make a guess estimate of what fraction of 0·1 inch the projecting part of the object might be. The process of measuring a fraction of a division is called *eye estimation* With a fair practice of eye-estimation a fractional part correct to a fifth of a division

can be estimated. If a reading lens is used each small division appears magnified and so with an ordinary reading lens and with a little practice, it is not difficult to measure one-tenth part of a division with eye-estimation. A careful observation reveals that the projecting part of AB beyond the 8th division is 0·4 of a division. Hence the length of AB is 0·84 inch.

It is to be noted that the method of eye-estimation is only an approximation and is, therefore, subject to some error. This means that in one case a measurement of a particular length may give a slightly larger value when the error is said to be positive. In another case the same length when measured may give a slightly smaller value when it is a negative error. In this way when a number of measurements is taken, it is found that results are distributed on both sides of the true value in such a way that their *arithmetic mean* is very nearly equal to the actual length. In practice five to ten readings are taken and their average value is found. The following illustration would make the proposition clear. Suppose that you are required to measure the length of a rod and you have taken ten measurements of its length in centimetres for different placings of the rod. The readings are as given below;

20·15; 20·10; 20·00; 20·18; 20·05; 20·02; 20·00; 20·15; 20·12; 20·14.

The sum total of the ten readings is 200·91 cm. and the mean value of the reading is 200·91/10 = 20·091 cm. This mean value represents the average length of the rod. It would be found that out of 10 readings, six are above the average and four below.* Two principal sources of errors arise out of the direct application of a metre scale. These are,—

(i) Parallax Error—This error arises out of the apparent change in the reading of the scale due to a change of position of the observer particularly when the graduated face of the scale and the object are not ordinarily on the same plane. In such a case the position of the eye influences the reading of the scale. In fig. 6, PQ represents a plate placed beside a metre scale. If observations be taken from the positions A and B, the line of sight being in both cases perpendicular to the plane of the scale, the reading corresponding to P 1 cm., and that corresponding to Q is 3·9 cm. and so the length of the plate is 2·9 cm. This is a more accurate method of measuring length of the plate. If, however, the positions of the eye be at C and D so as to get inclined vision, the end P appears to read 1·2 cm. and

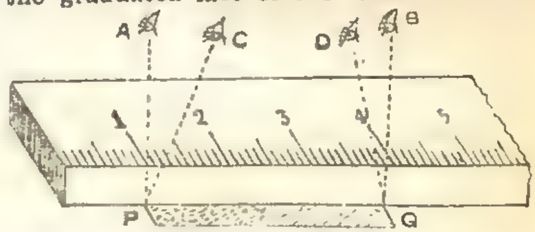


Fig. 6—Effect of Parallax

*In a set of readings, one or two observations may occasionally be found to be *much higher or much lower* than the mean value. These are called spurious readings and arise out of chance or carelessness. These are absurd data and should be discarded in evaluating the mean value.

Q 3'8 cm. and, therefore, the length apparently becomes 2'6 cm., which is 0'3 cm. less than the former value. It is, therefore, evident that the length of an object measured along oblique vision entails an error which is called the Parallax Error. **To avoid the parallax error** the line of sight must **always be normal to the scale** and the object must be placed **parallel to the scale** while making measurement.

(ii) **Irregularities of Graduations**—This error is due to the defect of the instrument used. The graduations of a scale in ideal conditions should be *perfectly* equidistant. But owing to the constructional defect of an actual scale, the distance between the consecutive graduations might be at some places very slightly shorter or longer than the actual value. Particularly the division at each extremity of the scale becomes positively shorter with a continued use because the ends wear our gradually. This is known as the **end effect** of a linear scale. Therefore, a single measurement of the length of an object at any part of the scale might prove a little too big or too small. End readings on a fairly old scale should be avoided as far as practicable.

To minimise the error due to irregularities of graduations the object which is to be measured in placed at different parts of the scale, and readings corresponding to its two ends are taken every time avoiding parallax and using eye-estimation. The difference of any pair of readings gives the length of the object with reference to that part of the scale. Finally, the arithmetic mean of a number of measurements gives the mean length. The body should not generally be placed touching any extremity of the scale.

The following procedure would simplify measuring a length at different partss of the linear scale ;—Call one end of the object, whose length is to be measured, as A and the other end as B. Make the end A coincident with any graduation of the scale. Let this be 10 cm. Place the object alongside the scale and read the end B with reference to the scale. If this reading be 22 14 cm. taken with eye-estimation, then the length is $22{\cdot}14 - 10 = 12{\cdot}14$ cm.

Inspection of the Measuring Scale—Whenever a measuring scale is supplied to you, the first thing is to determine or examine the unit in which the scale is graduated. If you find that markings 1, 2, 3 etc. happen to lie at approximate distance of the width of two fingers, then the scale is an inch scale. Then count the number of subdivisions in an inch as given on the scale. If there are m divisions over an inch length, then the value of the smallest division of the scale is $1/m$ inch. On the other hand if the markings 1, 2, 3 etc., are at distances of a little less than the width of the finger, it is a centimetre scale. Generally you would find that each centimetre length is subdivided into ten equal parts. Then the small space between two consecutive graduations is a millimetre. If there is any confusion regarding the nature of the scale, it is always safe to compare the scale supplied with a known scale, which you carry within the geometrical instrument box.

Date—

EXPERIMENT 1.

To Measure with an Ordinary Scale the Length of an Object

Theory—If a be the reading in any unit on the linear scale corresponding to one extremity of the object and b be the reading in the same unit corresponding to the other extremity, the required length is then equal to $a \sim b$ units *of length*.

Apparatus—A metre scale and a thin glass rod (or whatever be the object supplied for mea urement).

Procedure—Place the glass rod alongside the centimetre scale and in contact with it. Make one end of the rod touch a particular graduation of the scale, and take the scale reading for that end (left-end reading). This gives the reading a of one end in cm. You will find that the other end of the rod lies generally at some other part of the scale within *two consecutive millimetre marks*. Read in centimetres the graduation of the scale nearest this end. Take a guess of the length of the projecting part beyond this mark in fraction of a millimetre by eye-estimation and add it to the scale reading by converting this fractional part into centimetre. This gives the reading b of the other end (right end reading). The difference of these two readings is the observed length of the rod in cm. Care must be taken to avoid parallax error as far as practicable. Place the rod at 5 to 10 different parts of the scale and take similar readings. The average value of the lengths measured in this way gives the mean length of the rod in centimetres.

Repeat a similar procedure by placing the rod in contact with the inch side of the scale and obtain the mean length in inches. As the same length is measured both in cm. and in inches, take the ratio of the observed lengths. This ratio gives the observed equivalence between centimetres and an inch.

Results–(A typical set of results is given here).

The centimetre side of the scale was used. The smallest division of this scale was found to be 1 mm = 0·1 cm. Eye estimation could be pushed down to 0·2 mm = 0·02 cm.

Length of	Left-end Readings			Right-end Readings			Length $(b-a)$	Mean Length
	Main Scale	Eye-Estimation	Total a	Main Scale	Eye-Estimation	Total b		
	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
A Glass Rod using Centimetre Scale.	10	0	10·00	33·5	0·06	33·56	23·56	23·56
	18	0	18·00	41·5	0·08	41·58	23·58	
	25	0	25·00	48·5	0·04	48·54	23·54	
	30	0	30·00	53·5	0·08	53·58	23·58	
	36	0	36·00	59·5	0·07	59·57	23·57	
	40	0	40·00	63·5	0·08	63·58	23·58	
	50	0	50·00	73·5	0·05	73·55	23·55	
	56	0	56·00	79·5	0·05	79·55	23·55	
	60	0	60·00	83·5	0·06	83·56	23·56	
	70	0	70·00	93·5	0·03	93·58	23·58	

The inch side of the scale was used. The smallest division of this scale was found to be 0·1 inch. Eye-estimation could be pushed down to 0·01 inch.

Length of	Left-end Reading			Right-end Readings			Length $(b-a)$	Mean Length
	Main Scale	Eye-Estimation	Total a	Main Scale	Eye-Estimation	Total b		
	inch	inch	inch	inch	inch	inch	inch	inch
The same Glass Rod using Inch Scale.	1	0	1·00	10·2	0·06	10·26	9·26	9·27
	3	0	3·00	12·2	0·05	12·25	9·25	
	6	0	6·00	15·2	0·07	15·27	9·27	
	10	0	10·00	19·2	0·08	19·28	9·28	
	13	0	13·00	22·2	0·07	22·27	9·27	
	16	0	16·00	25·2	0·08	25·28	9·28	
	20	0	20·00	29·2	0·07	29·27	9·27	
	23	0	23·00	32·2	0·06	32·26	9·26	
	26	0	26·00	35·2	0·09	35·29	9·29	
	30	0	30·00	39·2	0·07	39·27	9·27	

Since 9·27 inches = 23·56 cm. (as observed,) 1 inch $= \frac{23·56}{9·27}$ $= 2·54$ cm.

Discussions—The principal sources of errors in taking readings are due to parallax and eye-estimation. These errors become very small by taking a mean of a large number of readings. Further, the *greater is the length to be measured, the smaller is the percentage of error.* Another source of a very small error is due to a change in length of material of the scale due to a variation of temperature. The amount of error due to temperature variation depends upon the expansibility of the material of the scale. For ordinary measurements of length the correction due to temperature variations, which is negligibly small fraction of a millimetre, is not therefore necessary.

To calculate the maximum percentage of error in reading the length of the rod, we find that the minimum reading for the length is 23·54 and maximum reading is 23·58. Hence the variation of reading is ·04 cm. in a mean length of 23·56 cm.

Therefore, maximum percentage of error $= \pm \frac{0·04 \times 100}{23·56} = 0·1\%$

The observed relation between an inch and a centimetre shows that the percentage of error is within ±·1% of the actual value.

Note that if the centimetre and inch scales are engraved on the two edges of any material of the scale, each side of the meterial will be affected equally by a change of temperature but the *equivalence between an inch and centimetres as found in the experiment will not be altered.*

Oral Questions

What is a parallax error and how can you avoid it? Why should you leave out the end divisions of a scale in using it? Why do you take a number of read-

ings in measuring a length? What are the units of length on the two systems and which one is more preferable? How many centimetres are equal to an inch? What is eye-estimation in measuring a length? Explain why a greater length can be more accurately measured than a lesser one.

Date—

EXPERIMENT 2

To find the Trigonometrical Ratios of 30° and 60°

Theory—If in a right-angled triangle ABC the $\angle C = 90°$, $\angle B = 30°$, $\angle A = 60°$ and if the lengths of the sides AB, BC, CA be x, y, z units of length respectively, then

$$\frac{z}{x} = \sin 30° = \cos 60° = \frac{1}{\operatorname{cosec} 30°} = \frac{1}{\sec 60°}$$

$$\frac{y}{x} = \cos 30° = \sin 60° = \frac{1}{\operatorname{cosec} 60°} = \frac{1}{\sec 30°}$$

$$\frac{z}{y} = \tan 30° = \cot 60° = \frac{1}{\cot 30°} = \frac{1}{\tan 60°}$$

Apparatus—Metre scale, set squares, protractor, reading lens, drawing paper and pencil. A large *right-angled triangle ABC with the aforesaid specification is to be drawn on the left side page.*

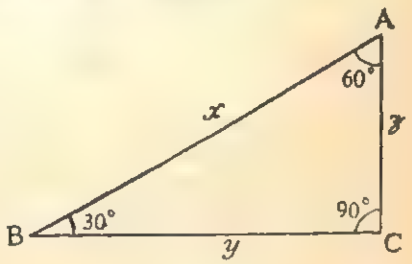


Fig. 7

Procedure—Place a set square having angles 30°, 60° and 90° on the drawing paper and draw an outline of it with a fine pencil mark. Put the letters B, A and C against the angular points 30°, 60° and 90°. Measure the lengths of the sides AB, BC and CA with a centimetre scale avoiding parallax and applying eye-estimation. Take three measurements for each side and find the mean length of each of the sides x, y and z. Make a tabulated chart as shown below and hence calculate the trigonometrical ratios of 30° and 60°.

Results—

Length of	Left-end Readings			Right-end Readings			Length $(a-b)$	Mean Length
	Main Scale	Eye Est.	Total say, a	Main Scale	Eye Est.	Total say, b		
	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
AB	20 40 60	0 0 0	20·00 40·00 60·00	33·5 53·5 73·5	·06 ·06 ·06	33·56 53·56 73·56	13·56 13·56 13·56	13·56
BC	30 50 80	0 0 0	30·00 50·00 80·00	41·7 61·7 91·8	·08 ·08 ·00	41·78 61·78 91 80	11·78 11·78 11·80	11·79
CA	20 40 70	0 0 0	20·00 40·00 70·00	26·7 46·7 76 7	·08 ·08 ·06	26·78 46·78 76·76	6·78 6·78 6·76	6·78

$$\therefore \quad \frac{z}{x} = \sin 30° = \cos 60° = \frac{6{\cdot}78 \text{ cm.}}{13{\cdot}56 \text{ cm.}} = 0{\cdot}500$$

$$\frac{y}{x} = \cos 30° = \sin 60° = \frac{11{\cdot}79 \text{ cm.}}{13{\cdot}56 \text{ cm.}} = 0{\cdot}869$$

$$\frac{z}{y} = \tan 30° = \cos 60° = \frac{6{\cdot}78 \text{ cm.}}{11{\cdot}56 \text{ cm.}} = 0{\cdot}575$$

Discussions—By applying eye-estimation and with a reading lens it is possible to measure every side of the triangle correctly upto a fifth of a millimetre, and so it is justified to express the length of each side upto 2 places of decimals in centimetres. But since the sides of the triangle are of different lengths, the relative accuracies of measurements of the sides are slightly different from each other. Suppose that the error of measuring each length is not more than $\pm{\cdot}02$ cm. Then the percentage of error in measuring 13·65 cm. is $\pm\frac{{\cdot}02}{13{\cdot}56} \times 100 = \pm{\cdot}14\%$. In a similar way it can be shown that the errors in measuring 11·79 cm. and 6·78 cm. are $\pm{\cdot}16\%$ and $\pm{\cdot}28\%$. Thus we see that measurement of larger lengths involves smaller percentage of errors; the longer are the sides of a triangle the more accurate are the ratios found. The average percentage of errors is ·2% which represents an error of 1 in 500. So the values of the ratios may be expressed very approximately upto 3 significant figures or upto 3 places of decimals.

The error for observed value of sin 30° upto the 3rd place is nil. The accepted value of sin 60° = 0·866 and the calculated value is 0·869. So the percentage of error is ·03%. The standard value of tan 30° = 0·577 and the calculated value is 0·575 and hence the percentage of error is also ·03%. So it is seen that the calculated pereentage of error is negligibly small.

From the other set square which is an equilateral right-angled triangle, the trigonometrical ratios of 45° can be found.

2.1. Metre Scale and Beam Compass—When the object is curved or uneven, it is inconvenient to place a metre scale alongside the object. In such a case a beam compass is conveniently used in measuring its length. A beam compass consists of a straight and uniform rod having two long pointers, which can be slided over and clamped anywhere on the rod. In some form of beam compass, the rod itself is graduated in centimetres or inches (Fig. 8).

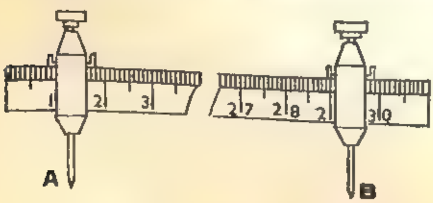


Fig. 8.—Beam Compass

To measure the distance between two points with a beam compass, fix one of the pointers by the screw cap near one end of the rod and make the tip of this pointer touch the point under observation. Now slide the other pointer over the rod till it touches the

second point. Fix up the second pointer there. Measure the distance between the ends of the pointers, which is evidently the distance between the points. In using a beam compass, with an ordinary metre scale as in Experiment 1, the procedure of adjusting the pointers is to be repeated a number of times. It is to be borne in mind that the length measured with a beam compass gives the *straight distance* between the two points under investigation and not the distance along the curved or uneven surface. The method of procedure and tabulation of data are identical with those of Experiment 1.

2.2. Metre Scale and Dividers—For measurement of short lengths, it is often convenient to use a pair of dividers. A pair of dividers consists of two metallic pointers hinged at the top such that the distance between the ends of the pointers can be altered continuously (Fig. 9*a*).

In order to keep the position of the pointers more steady some form of dividers is controlled by an adjustable side screw (Fig. 9*b*). The experimental procedure of measuring a distance with dividers is similar to that of a beam compass. But since shorter lengths are generally measured with dividers, the percentage of error in this case is greater than that of a beam compass. A pair of dividers may conveniently be used to measure length along curved paths as given below.

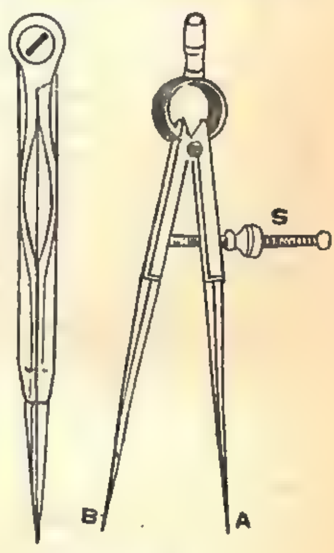


Fig. 9—Dividers

2.3. Length of Curved Lines—If we divide a curved line into a number of very short segments, then each segment may be considered approximately as a straight line and if the lengths of all these segments are added, we get very approximately the entire length of the curved line. This is one practical method of measuring the length of a curved line. The short equal segments are marked out with a pair of dividers. Finally, knowing the number of segments thus made and the length of the segment, the entire length between the two points is obtained.

The measurement of distances over straight or curved lines on a map or a survey plan of a drawing on a specified scale is often made with a divider. For example, the distance between any two stations over straight or curved railway track or the length of a river as shown on a map may be conveniently measured by adjusting the points of the divider to a suitable small scale as supplied on the map and counting how many such segments make up the required length.

Date—

EXPERIMENT 3

To Measure the length of the Circumference of Circle and hence to find the Ratio of Circumference and Diameter

Theory—If the circumference of a circle be divided into a large number, say n, of very small segments each of length l, then the length of the circumference of the circle is equal to nl units. Let the length of its diameter be d in the same unit. The standard ratio of circumference of a circle and its diameter is constant and is called π.

Apparatus—Drawing board, paper, compass, divider and a metre scale.

Procedure—Draw three concentric circles of radii of approximately 5, 6 and 7 centimetres with a compass on a piece of drawing paper and draw two diametres for each circle. Measure in centimetres the length of each diameter with a metre scale avoiding parallax and using eye-estimation. The mean length of the two diameters for any circle gives the average diameter of that circle in centimetres.

Now take a pair of dividers and place the pointed ends on a metre scale. It is advisable to take a reading glass and with the help of this glass adjust the distance between the two points of the divider so that it is made 0·5 cm. This adjustment is to be made *as accurately as possible.* Then place the divider on the outermost circle such that two dots are imprinted on its circumference. The segment between the dots is evidently 0·5 cm. In this way count the number of such segments on the whole circumference of a circle. The last segment would generally be a fraction of 0·5 cm. Measure this last segment directly with a metre scale or another divider. Add together the lengths of all the segments and also the last fractional part. This gives the length of the circumference of the circle. Make two measurements for each circumference and calculate in each case the ratio of the circumference to diameter. Finally find the mean of all these ratios.

Results—

The distance between the points of dividers = 0·5 cm. = the length of the segment (say).

Object to be measured / Circumference of	Number of segments	Length of each segment	Length of last segment	Length of circumference	Diameter	Ratio of circumference and Diameter	Mean value of observed Ratio π
		cm.	cm.	cm.	cm.		
Outermost Circle	91	0·5	0·3	45·8	14·6	3·13	
	92	0·5	0·0	46·0	14·6	3·14	
Intermediate Circle	76	0·5	0·4	38·4	12·3	3·13	3·13
	77	0·5	0	38·5	12·3	3·13	
Innermost Circle	62	0·5	0·4	31·4	10·05	3·13	
	62	0·5	0·3	31·3	10·05	3·13	

Discussions—In using divider to measure the length of the circumference what is measured is practically the total length of a number of small chords around the circle. Since a chord is always less than the corresponding arc, it follows that measured circumference should be slightly less than its actual value. So the calculated ratio of the length of the circumference to the diameter of a circle should be less than the accepted value of π. In the above experiment in five cases out of six the value of π is found less. There is another source of error which affects the result greatly, and that is, any error in measuring the length of one segment would be multiplied a large number of times in the calculation of the length of the circumference. The accepted value of π being 3·14, the percentage of error for the mean value of 3·13 is 0·3%.

3.1. Metre Scale and Simple Callipers—The simple callipers consists of two similar pieces of metal hinged like a pair of scissors (Fig. 10). It is usually used for measuring the internal and the external diameters of pipes, tubings or hollow vessels. The upper pair of arms is meant for external diameter and the lower pair for internal one.

In order to measure the external diameter of a pipe, the upper arms are opened sufficiently to allow the pipe to slide into the space such that the two extremities of the jaws touch the opposite points of the external diameter of the pipe. The distance between the two jaws is measured with reference to a metre scale. A number of readings is taken for different positions of the diameter and their mean value is found which gives the average diameter. To measure the internal diameter of a cylinder the lower jaws are introduced within it and are then opened so as to touch the inside surface at two diametrically opposite points. The distance between the points of the jaws is measured with reference to a metre scale. A number of readings is taken at different positions of the diameter and the mean value represents the internal diameter.

Fig. 10

Exercises

1. Draw on a white sheet of paper three straight lines of unequal lengths and measure the length of each in centimetres and inches. Hence, find the relation between an inch and a centimetre. Why is it that the relation can be more accurately found from measurement of a larger length?

2. Draw a right-angled isosceles triangle on a piece of paper and calculate the trigonometrical ratios of 45°.

3. Draw two curved lines on a piece of paper and measure the length of each with a pair of dividers in centimetres and inches. Hence, find the equivalence between an inch and a centimetre.

4. Find the mean external and internal diameters of a copper calorimeter with simple callipers.

5. Find the volume of a solid uniform cylinder in cu. inches and in c.c. by measuring its length and diameter with the help of the formula, volume = length × (half the diameter)^2 × 3·14.

3.2. Diagonal Scale—The accuracy of reading a fraction of a millimetre or an inch is impaired by eye-estimation, since different persons might guess different fractions for the same length. To minimise such uncertainties of eye-estimation a modified inch or centimetre scale, known as a diagonal scale, may be used.

Fig. 11 represents a multipurpose scale engraved on a metal or celluloid rectangular sheet. One face of the scale, as represented by the left half of Fig. 11, is the inch scale ; the upper edge numberings are in inches having one-tenth inch graduations and the lower edge graduations are in one sixteenth inch. The parallel oblique lines at the middle region is the diagonal inch scale The other face of the scale, as represented by the right half of Fig. 11, has centimetre scale on the upper edge and an angular scale on the lower and right vertical edges. To understand the principle and use of a diagonal scale, a separate diagram for this part is given in Fig. 12. The usual inch graduation begins from the zero mark of the bottom line to the right. The width FW of the scale is accurately divided into ten equal parts by equidistant horizontal lines drawn over its entire length. There is also an inch extension to the left of the zero line. This extension inch scale is subdivided into 10 equal parts both at the top and bottom, marked 1, 2, 3......10. A series of oblique parallel lines connecting 1 and 0, 2 and 1, etc., are drawn across the scale as shown (Fig. 12). These straight lines are known as diagonal lines, whence the name of the scale is derived.

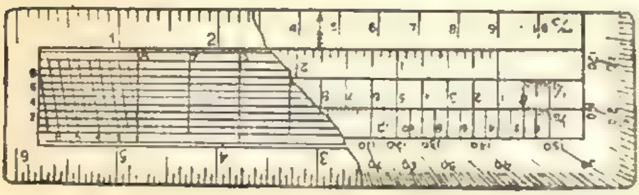


Fig. 11—Diagonal Scale

Each subdivision between the oblique lines is evidently 0·1 inch. Consider the geometry of the triangle formed by the vertical line 00 and the diagonal line 01. This triangle is intersected by a series of horizontal parallel lines. These intercepts continuously increase

Fig. 12

in length from ·01 inch at the bottom to 0·1 inch at top in steps of ·01 inch.

To measure the length of a rod, say MR, the following procedure is to be adopted. Place one end R of the rod in line with a

graduation of the inch scale (as shown in Fig. 12) R coinciding with vertical line 2, so that its other end M projects into the diagonal scale. Then it can be inferred that the length is 2 inches plus some fraction of an inch. Now slowly lower down the rod from the top line, the end R all the time touching the same inch graduation. Examine the end M and suppose that this end *touches a diagonal line* when it is on the 8th horizontal line *counting from the bottom.* It is evident from the figure that the length RM is greater than 2 inches but less than 3 inches. The projecting part of RM into the diagonal scale is the fractional part of an inch. The projecting part is found to occupy three small divisions between diagonal lines 4-3 and 1-0 ; as also another part between triangular lines 010. The fractional length of MR between the diagonal lines 4-3 and 1-0 is 0·3 inch. Since the fractional part within triangular lines 010 is on the 8th parallel, this part is ·08 inch. Hence the total fractional part is 0·38 inch. Thus the total length comes out to be 2·38 inches. In a similar way, it is seen that the length ST is 1·13 inches.

Although we can measure the length of an object with a diagonal scale correctly to ·01 inch, there is a great possibility of making parallax error in reading the ends of the object. A divider is often used with a diagonal scale. Still when the divider is placed at the ends of the object there is a possibility of making a parallax error much more than ·01 inch.

3.3. Vernier Scale—For measuring accurately a small fraction of a centimetre or an inch a linear vernier scale is used. It was first constructed by a French scientist Pierre Vernier. It consists of a short auxiliary scale called the vernier scale which can slide along the edge of the main scale (Fig. 13).

Principle of a Vernier—On examining the main and the vernier scales it is found that the graduations of the scale are not identical but a certain number of divisions, say n, of the vernier scale is equal in length to a number of divisions $n-1$ of the main scale. When the length of a vernier division is less than that of a main scale division, we call this system a **forward reading vernier.** The total numbers of divisions found with a vernier scale of the callipers are usually 10, 25 or 50.

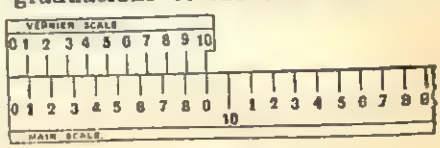


Fig. 13

Vernier Constant—The smallest length that can be measured with a vernier scale in conjunction with a main scale is called the **vernier constant** or the **least count** of the vernier. To find the vernier constant the vernier scale is slided over the main scale until the vernier zero line is coincident with a main scale division as shown in the figure. It would then be found that the last division of the vernier scale is coincident with another main scale division. Then the number of vernier divisions and the number of equivalent

main scale divisions are counted. In Fig. 13, 10 vernier divisions are equivalent to 9 main scale divisions. In general, if n divisions of the vernier scale cover a length equal to $n-1$ divisions of the main scale, then n vernier divisions $= n-1$ main scale divisions

or 1 vernier division $= \frac{n-1}{n}$ of a main scale division

$\therefore$ 1 scale division $-$ 1 vernier $= \left(1 - \frac{n-1}{n}\right)$ of a main scale division $= \frac{1}{n}$ of a main scale division.

The difference between one main scale division and one vernier division is equal to the vernier constant or the least count of the vernier. The latter term means that this difference is really the *least distance which can be measured* with a vernier.

In Fig. 13, it is found that 10 vernier division (*v.s.*) are equivalent to 9 main scale divisions (*m.s.*).

Therefore, 1 $v.s. = \frac{9}{10}$ *m.s.* or 1 $m.s. - 1 v.s. = \frac{1}{10}$ $m.s. = 0{\cdot}1$ *m.s.* That is to say that the least count of the particular vernier is one-tenth of the main scale division. If the *smallest division* of the main scale is a millimetre, the least count is 0·1 mm. If, on the other hand, the main scale is graduated in 0·1 inch, the least count becomes ·01 inch.

3.4. Application of a Vernier Scale—Suppose that we are to measure the length of a rod AB using a millimetre scale with a vernier attachment. We have to find at the start the vernier constant following a method as described in the preceding article. Let the least count of the vernier be 0·1 mm. (Fig. 14). Now we slide the vernier over the main scale and examine whether the zero of the vernier coincides with zero of the main scale. If it is so, then there is *no instrumental error*. But if the zero of the vernier does not coincide with the zero of the main scale, there is some instrumental error which would be described in the next Article. Let us suppose that there is no instrumental error in this case. We then place the end A of the rod so as to be coincident with the zero of the main scale. The vernier is then slided so as to touch the end B of the rod. The vernier zero line which touches the end B of the rod lies somewhere between the 8th and 9th divisions of the main scale. This means that the length of the rod is 8 mm. plus some fraction in millimetre. In order to read this fractional part we should look at the position of contact of the two scales marks. In this particular case it is to be noticed that the 6th vernier division is in line with a main scale division. Therefore, the displacement of the vernier zero from the 8th main scale is 6 times the least count, *i.e.*, 0·6 mm. Thus, the total length of the rod is $(8+0{\cdot}6)$ mm. $= 8{\cdot}6$ mm. $= 0{\cdot}86$ cm. In practice,

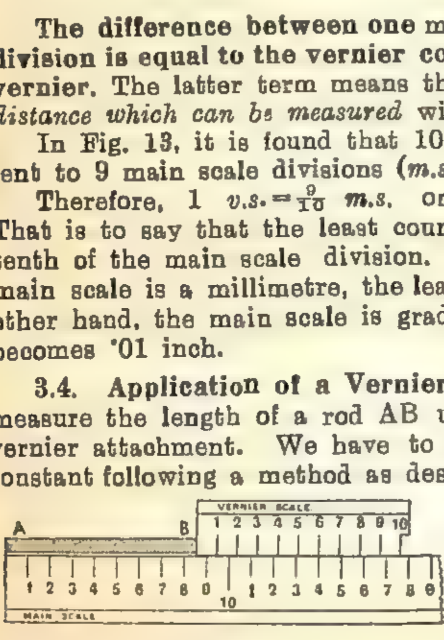


Fig. 14

we should take a number of readings for the length of the rod find the mean value for the length AB.

To Measure a Vernier Constant the following procedure is to be adopted—(i) Slide the vernier scale over the main scale and adjust it to such a position that the zero-line or the base-line of the vernier (usually marked with an arrow-head) exactly coincides with any graduation of the main scale.

In this position the *last mark* of the vernier scale would be found to coincide with another graduation of the main scale.

(ii) Count the number of divisions of the vernier scale as also the number of divisions of the main scale between the two lines of coincidences. Let n vernier divisions be equal in length to $n-1$ main scale divisions. Then 1 main scale division $=\frac{n-1}{n}$ vernier divisions. Then the vernier constant is equal to $\frac{1}{n}$ of a main scale division.

(iii) Find the value of *one* of *such main scale divisions* with reference to the original or an auxiliary scale or with a pair of dividers and a metre scale.

Let the value of *one* of the n divisions of the main scale $=l$ mm. or inch, as the case may be.

Then vernier constant $=\frac{1}{n}\,l$ mm. or inch. Suppose that $l=1$ mm. and $n=10$. Then vernier constant $=0\cdot1$ mm $=\cdot01$ cm.

Backward Reading Vernier—This type of apparatus is very much less in use. It consists of a main scale and sliding vernier scale (Fig. 15). The number of divisions on the vernier scale is one less than the number of divisions on the same length of the main scale. The graduation marks of the vernier scale are opposite to those of the main scale. Hence it has derived the name of a backward reading vernier. Let n divisions of the vernier scale be equivalent to $n+1$ divisions of the main scale.

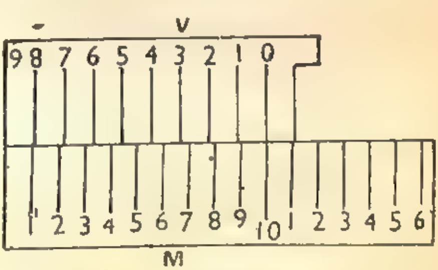


Fig. 15

Then 1 *vernier scale* $=\frac{n+1}{n}$ main scale

$\therefore$ 1 $v.s.-1$ $m.s.=\frac{n+1}{n}-1=\frac{1}{n}$ main scale

So the least count is nth part of the main scale as in other class of verniers. To use it, place the object as usual and take the main

scale reading nearest the last mark of the vernier, this represents the integral part. Now find the vernier division in coincidence with the main scale mark. Then main scale reading plus the vernier reading × the least count gives the required reading for the length.

Examples :

1. On adjusting a vernier scale, 10 vernier divisions are found to be equivalent to 9 main scale divisions. The value of such a main scale division is 1 mm. Find the vernier constant.

A. Here $n=10$ and $l=1$ mm.$=0\cdot1$ cm. Hence vernier constant$=\frac{1}{10}\times\cdot1$ $=0\cdot01$ cm.

2. 25 vernier divisions are found to be equal to 24 scale divisions. 1 inch is divided into 20 such scale divisions. Find the least count of the vernier.

A. Here $n=25$ and $l=\frac{1}{20}$ in.$=0\cdot05$ in. Hence least count$=\frac{1}{25}\times0\cdot05=0\cdot002$ in.

3. In a Fortin's barometer 10 div. of the vernier scale are found to be equal to 19 div. of the main scale. The main scale div. is 0·5 mm. Find the least count.

A. To make a difference of unity in the two scale divisions, imagine that each vernier division is divided into two parts to make the total number of divisions equal ot 20.

Then $n=20$ and $l=0\cdot05$ cm. Hence least count$=\cdot0025$ cm.

But since the value of the actual vernier divisions is double the value of the divisions imagined, the vernier constant is also double the value found. Hence the vernier constant is $2\times\cdot0025=0\cdot005$ cm.

3.5. Vernier Callipers—A vernier callipers consists of a thin steel scale M with a jaw A fixed at one end at right angles to its length

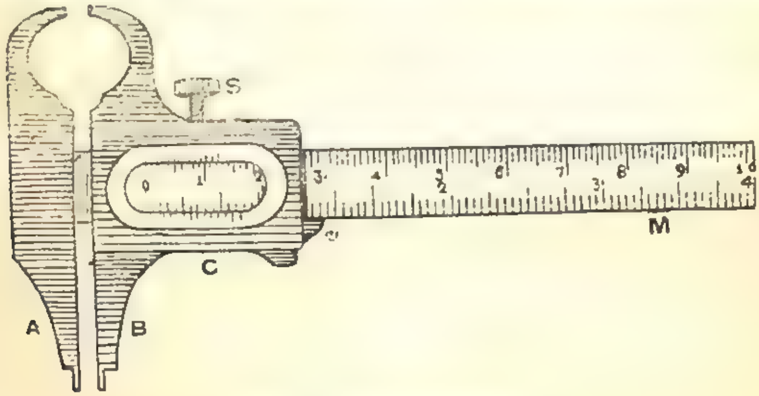


Fig. 16—Vernier Callipers

(Fig. 16). The other jaw B can be slided over the scale and can be fixed at any position by means of a screw S. The movable jaw is provided with an extension C on which there are two vernier scales, one on each side, corresponding to the two main scales of the steel bar. The upper main scale is generally graduated in millimetres and the lower end in one-twentieth of an inch. Usually, 10 vernier divisions coincide with 9 main scale divisions on each side, so that the vernier constant is $\frac{1}{10}$ of main scale value. So the least count of the upper vernier is 0·1 mm. and that of the lower is 0·005 inch in the above case.

When the two jaws A and B are brought in contact, the zero of the vernier should generally coincide with the zero of the main scale. The instrument is then said to have no zero error. With a correct instrument as this, if the jaws are separated, the distance between their edges is equal to distance between the zero of the main scale and the zero of the vernier scale. The object, whose length is to be measured, is placed between the jaws so as to fit in exactly. Then the readings of the main and vernier scales are taken in the usual manner, which give the length of the object in terms of the scale used. A callipers is used for measuring lengths of rods, diameters of balls and of cylinders and internal diameters of tubings.

Instrumental Error or Zero Error—Some vernier callipers, with a continued use, develop an error in which the vernier zero line does not coincide exactly with the main scale zero when the jaws are placed in contact. This lack of coincidence might be due to wear and tear of the instrument. When there is a case like this, we call this defect an instrumental error or zero error. With an instrument having zero error, the actual reading on the scale does not give true length of a body placed between the jaws. There may be two types of instrumental error—

(*a*) When the jaws are placed in contact, the zero of the vernier is *in advance of the zero line of the main scale* by a little amount, say x mm. This means that while the instrument should have given the reading zero, it is apparently giving a reading $+x$ mm. On now placing a body between the jaws, if the reading on scale shows to be y mm. then the actual length of the body is $(y-x)$ mm. In fig. 17, the vernier zero is in advance of main scale zero by an amount 0·2 mm. So the instrumental error is +0·2 mm.

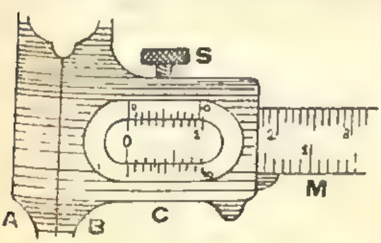


Fig. 17.

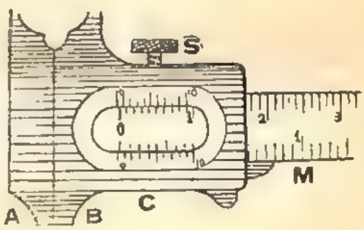


Fig. 18.

Therefore, the length of the body = actual reading on the scale − instrumental error. In this case the instrumental error is positive and has got always to be substracted from the actual reading.

(*b*) When the zero of the vernier is behind that of the scale by an amount x mm. incase the jaws are in contact, the instrumental error is negative in such a case. Then with a body within jaws if the reading be y mm., then the actual length is $(y+x)$ mm.

Thus, the true length of the body = actual reading on the scale − the instrumental error. In fig. 18 the vernier zero is behind the main sacle zero by an amount −0·7 mm. Hence this quantity is to be added to the observed length.

You always remember a very reasonable argument that the reading of a length containing the instrumental error is mathematically equal to the actual length + instrumental error. Therefore *apparent length − instrumental error = actual length.*

Date— EXPERIMENT 4

To Measure the Length of a Rod with a Vernier Callipers

Theory—If n vernier divisions are equivalent to $(n-1)$ scale divisions, the vernier constant is nth part of a scale division. The apparent length of the rod placed between the jaws of the callipers is the sum of the main scale reading and the vernier reading × the least count of the vernier. If the reading of the vernier be $+l$, when the jaws are in contact; this is instrumental error. The actual length of the rod is then apparent length *minus* the instrumental error.

Apparatus—A slide callipers and a rod.

[A brief description of a slide callipers is to given here. A sectional diagram of slide callipers is to be drawn on the left side page.]

Method of Procedure—Slide the vernier scale over the main scale so that the zero line of the vernier scale coincides with a main scale graduation. Now look for the coincidence of the last division of the vernier with another main scale division. Then count the total number of divisions of both the vernier and main scale *between these two coincident points.* Record these observations under the heading 'Results'. To be sure of these numbers slide the vernier scale to some other place of the main scale and re-check the numbers. Determine the value of main scale division with reference to a measuring scale. Then calculate the vernier constant.

Now place the two jaws of the callipers in contact. If the vernier zero exactly coincides with the main scale zero, there is no instrumental error. Re-check your observation a few time to be sure of your inference. But if the zero of the vernier is to the left of the zero of the main scale (*i.e.*, towards the fixed jaw), when the jaws are in contact, the reading would be negative but the correction would come out to be positive, which means that it is to be added to all subsequent readings for any length. But at the position of contact, if vernier zero is to the right of main scale zero, the error is positive and the the correction is negative. Take three readings for the instrumental error and find the mean value. This gives the mean instrumental error, if any, positive or negative (*vide* Art. 3·5).

Next place the rod between the jaws, with its one end touching the fixed jaw and other in contact with the movable one taking care that the rod is not too tightly pressed between the jaws.* Take the main scale reading just short of the vernier zero line and tabulate under the column (*a*). Count the number of the vernier divisions in line with a main scale division and tabulate this number

*If the rod is too tightly pressed between the jaws, the rod may be slightly compressed or the jaws may be temporarily or permanently bent or both might happen.

under the column (*b*). The product of this number and the vernier constant gives the length of the fractional part. The sum of the two gives the apparent length of the object. Take at least *five* readings for the length and arrange in the tabular form. Calculale the mean value. Finally, add or subtract the instrumental error as the case may be and get the mean length of the object.

Results :—Determination of Vernier Constant :—(*a*) For the Centimetre Scale, 10 *v.s.* = 9 *m.s.* (say) ∴ 1 *v.s.* = 0.9 *m.s.*

The Least Count = 1 *m.s.* − 1 *v.s.* = 1 *m.s.* − 0·9 *m.s.* = 0·1 *m.s.* The main scale is found to be graduated in millimetres.

∴ Least Count of the Vernier = 0·1 mm. = 0·01 cm.

(*b*) For the inch scale, 10 *v.s.* = 9 *m.s.* Therefore least count = 0·1 *m.s.* and the main scale is graduated in $\frac{1}{20}$ *inch* = 0·05 in.

∴ Least Count of the Vernier = 0·1 × 0·05 = 0·005 inch.

To determine the instrumental error :—

No. of reading	Centimetre Side				Inch Side			
	Main scale	Vern. scale	Total cm.	Mean cm.	Main scale	Vern. scale	Total in	Mean in.
1.	0	4	0·04	0·04	0	3	0·015	0·015
2.	0	4	0·04		0	3	0·015	
3.	0	4	0·04		0	3	0·015	

Since the contact reading is positive, the instrumental error is positive in both units and is to be subtracted from the apparent readings or the mean of the apparent readings.

Measurement of Length of the Rod :—

Scale used	No. of readings	Main scale (*a*)	Vernier scale (*b*)	Fractional Part *b* × *l.c.*	Total Length	Mean Length	Instrumental Error	Corrected Length
		cm.		cm.	cm.	cm.	cm.	cm.
Metre Scale	1	7·2	2	0·02	7·22	7·23	−0·04	7·19
	2	7·2	3	0·03	7·23			
	3	7·2	3	0·03	7·23			
	4	7·2	2	0·02	7·22			
	5	7·2	3	0·03	7·23			
		inch.			inch.	inch.	inch.	inch
Inch Scale	1	2·80	9	0·045	2·845	2·847	−0·15	2·832
	2	2·80	9	0·045	2.845			
	3	2·80	8	0·040	2·840			
	4	2·85	1	0·005	2·855			
	5	2·85	0	0·000	2·850			

Discussions—The mean apparent length is 7·23 cm. The greatest apparent length is 7·23 cm. and the least value is 7·22 cm. So the variation of observed length from the mean value is ±·01 cm. This gives an error of ±0·01 cm. in a length of 7·19 cm. Therefore percentage of error $= \frac{\pm\ \cdot 01}{7\cdot 19} \times 100 = \pm 0\cdot 14\%$. Similarly, on the inch side taking the probable error to be one division of the vernier, the error comes out to be ±0·005 inch in a length of 2·832 inches, *i.e.*, a percentage of error or ±0·17%. Thus, it clearly shows that with such a form of vernier we can expect to measure a length in cm. with a slight greater accuracy than in inches.

A source of error is due to the temperature variation of the material of the scale, since every scale division which was correctly graduated at a definite temperature, undergoes a change in length at an altered temperature. This is, however, so small for moderate changes of temperature that the effect due to the variation may be neglected for the present. This correction is necessary when a length is to be standardised.

4.1. Relation between the Units of Length

To find experimentally the relation between the F.P.S and C.G.S. units of length a similar experiment as described in Expt. 4 may be done. The theory should be written as follows.

If the length of an object measured in centimetres be x cm. and that measured in inches be y inches then y in. $= x$ cm. Therefore, 1 inch $= x/y$ cm.

The apparatus, method of procedure and tabulation for experimental results are exactly the same. An additional vertical column should be added to the table giving the ratio of x and y. In the particular experiment it is found that 2·832 in. $=$ 7·19 cm.

$$\therefore \quad 1 \text{ inch} = \frac{7\cdot 19}{2\cdot 832} = 2\cdot 54 \text{ centimetres.}$$

In the discussions, it should be stated that the percentage of error in measuring the length in centimetres and that in inches can not exceed more than 0·14% and 0·17% respectively. Hence in determining the ratio of x and y the percentage of error would be much more less. In fact, the experimental value of 1 inch $=$ 2·54 cm. comes out correct up to two places of decimals.

Oral Questions

What is the principle of construction of a linear vernier scale? What is the distinction between a forward reading and a backward reading vernier? What is meant by the least count of a vernier? Is there any question of parallax error in reading a vernier? What is the accuracy with which a length of 5 cm. may be measured with a vernier scale having a least count of ·01 cm.? Is this accuracy greater or less when the distance of a mile is measured with a chain whose links are all one foot in length? In measuring a length with a vernier scale, it is found that no vernier line is exactly coincident with a main scale line; how you measure vernier callipers possesses least count; how would you judge the length of a rod in such a case?

4.2. Inside and Outside Vernier with Depth Gauge

One form of vernier callipers is provided with arrangements to measure the diameter of a rod, the internal diameter of a hollow pipe and the depth of a hollow cylinder (Fig. 19). It consists of a straight steel bar M with one edge graduated in centimetres and the other in inches. One end of the bar ends in two fixed jaws J_1 and

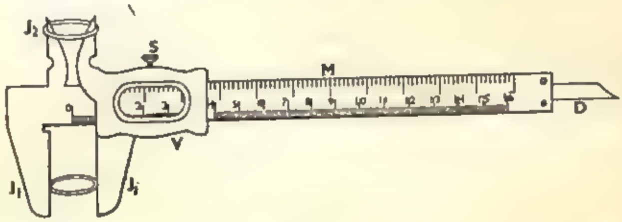


Fig. 19

J_2. A movable attachment carrying two vernier scales is also provided with two identical jaws J_1 and J_2. The scales are graduated in such a way that when the vernier reads zero of the main scale, the straight portion of the edges of the lower and upper jaws are in contact. There is a straight groove cut along the entire length of the bar along its back side, through which a thin uniform steel rod D can slide. One end of this rod is fixed rigidly to the vernier attachment and is of such length that when the vernier reads zero, the other end of the rod is in line with the end of the steel bar. Therefore, when the vernier moves over the main scale by a certain length, the end of the rod projects beyond the bar by an equal length. The instrument can be used as,—

(i) **Outside Vernier**—For measurement of external diameter of a rod, pipe or ring, the lower jaws J_1 J_1 are used and the method of measurement and procedure is just like that of the ordinary vernier callipers. The manner of placing a ring within J_1 J_1 for measurement is shown in the Fig. 19.

(ii) **Inside Vernier**—For measurement of internal diameter of a pipe, ring or cylinder, the upper jaws J_2 J_2 are used. The jaws are introduced within the hollow of the object and then gradually widened so as to touch the opposite ends of the diameter and usual readings are taken. In the particular figure the inside vernier is adjusted to measure the internal diameter of a ring.

(iii) **Depth Gauge**—To measure the depth of a hollow body, the scale is usually made vertical and the end of the main scale M is made to touch the rim of the body. The vernier is then slided to such an extent that the end of D touches the bottom of the hollow. The vernier callipers is then taken out and usual reading is taken.

Of course in all these measurements the instrumental error, if any, must be taken into consideration and a number of readings are to be taken exactly like that of an ordinary vernier callipers.

Exercises

1. Measure the internal and external diameters of a glass tube or copper calorimeter with a vernier callipers.

Hints :—Theory and apparatus are similar to those of Experiment 4.

The method of procedure is also similar, only the pair of jaws of the callipers meant for external diameter is to be used for external diameter and the other pair for internal diameter of the glass tube.

The nature of tabulation of data and discussions are also similar.

2. Determine the volume of a prism with a vernier callipers.

Hints :—In theory, add that volume of a prism is equal to the area of the triangular base ($\frac{1}{2}$ base $\times$ altitude) multiplied by the height of the prism.

In the method of procedure, the base length is to be measured by placing the prism within the jaws in such a way that any two angular points of the base touch the jaws. The altitude of the triangular base is measured by placing the prism such that the base plane touches one jaw and the vertex touches the other jaw. The height is measured by placing the length of the prism within the two jaws. Of course in each case the zero error is to be corrected for.

3. Determine the capacity of a copper calorimeter with a vernier callipers.

Hints :—In theory, add that internal capacity of a copper calorimeter is equal to the depth of the calorimeter $\times$ internal area of cross-section ($l \times 3{\cdot}14 \times r^2$).

In procedure, measure the internal diameter at several regions and take the mean. Half this value gives the radius r. To measure the depth, lower down a long and straight pin into the calorimeter till it touches the bottom. Measure the length of the projecting part of the pin with a metre scale or callipers. Measure the entire length of the pin. The difference of these two gives the depth of the calorimeter. Then, from the equation find the capacity either in cubic centimetres or cubic inches.

4. Measure the volume of a sphere.

Hints :—In theory, add that the volume of a spher is equal to $\frac{4}{3} \times 3{\cdot}14 \times r^3$, where r is the radius of the sphere.

To measure the radius of the sphere, place it such that the opposite ends of any diameter touch the jaws of the vernier. Thus, diameters at several places are determined. Hence the radius being known, volume may be found either in cubic centimetres or cubic inches.

5. Measure the volume of the given solid cylinder.

Hint :—In theory add that the volume of a solid circular cylinder is equal to the area of cross-section of the cylinder multiplied by its length.

In procedure, measure the diameter with a vernier calipers at several regions and take the mean value of the diameter in cms. Half of this value gives the radius r. Now measure the length of the cylinder in cms. Then $3{\cdot}14 \times r^2$ gives the area of cross-section is sq. cm. The product of the length and area of cross-section gives volume in cubic centimetres.

4.3. Micrometer Screw Gauge

For measurement of small thickness such as the diameter of a wire, an apparatus known as a Micrometer Screw Gauge is very suitable. It consists of a U-shaped body of steel, one arm of which carries a fixed stud A with a carefully planed terminal (Fig. 20). The other arm C acts as a nut in which a screw is worked by a drum D. This drum has got a bevelled end over which a circular scale is engraved (a part of which is seen bearing marks 50, 60 and 70). The circular scale contains 50 or 100 divisions. The arm C is provided with a linear scale,—most frequently a millimetre scale. As the drum D is rotated its collar gradually covers or uncovers the linear scale.

The screw is so evenly cut that for every complete turn it always moves through a fixed distance called the *pitch* of the screw. The screw terminates in another similar stud B moving in line with A. There is a friction clutch E at the terminal of the drum. It is always advisable to rotate the drum by holding the clutch. When the studs touch each other with a soft pressure, the clutch would no longer rotate the drum but it would slip over it. This appliance is for the safety of the milled heads.

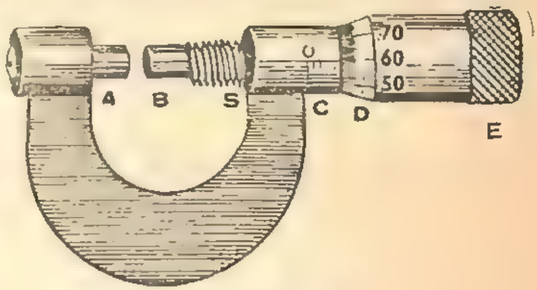


Fig. 20—Screw Gauge

Principle of Operation—The instrument operates on the principle that when a very accurately cut screw works in a nut, the linear distance through which the screw moves is proportional to the amount of rotation given to it.

Pitch of Screw Gauge—To find the pitch, rotate the friction clutch so that the drum uncovers a few divisions of the linear scale. Now compare the divisions of this scale with a laboratory scale, or if necessary with a pair of dividers and determine the value of the *smallest division* of the scale in centimetre or inch as the case may be.

Then with the help of the friction clutch bring the edge of the bevelled head of the drum *on any graduation* of the linear scale and mark the reading of the circular scale against the reference line (horizontal line) of the linear scale (as shown in the figure 20, the circular division coinciding with the reference line). Now slowly rotate the circular scale always observing what reading of this scale passes by the linear scale. When the same circular scale mark would come against the linear scale, observe the position of the edge of the collar. The circular scale has evidently been rotated through *one complete turn* and the amount of linear movement of the collar on the linear scale is the pitch of the screw gauge. If the pitch of the screw is n mm. and if the total number of circular divisions on the micrometer head be m, then for a rotation of m divisions of the screw, it moves linearly through n mm. Therefore, for rotation of 1 division of the circular scale, the micrometer head moves the screw through a distance n/m mm. This quantity is called the **least count*** of the micrometer.

Thus in general,—

$$\text{Least Count} = \frac{\text{Pitch}}{\text{Number of Circular Scale Divisions}}$$

*For example, if the pitch of a screw gauge is found to be 1 mm., and number of circular scale divisions be 100; then, the least count of the instrument is $\frac{1}{100}$ mm. $=$ ·01 mm. $=$ ·001 cm.

Instrumental Error—It is often found particularly with old instruments that the micrometer zero and the main scale zero are not coincident when the studs are in contact. The micrometer zero may be behind or in advance of the main scale zero by a certain number of divisions r of the circular scale. If the count is c, then the instrumental error is either $+rc$ or $-rc$ according as the circular

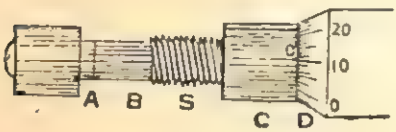


Fig. 21

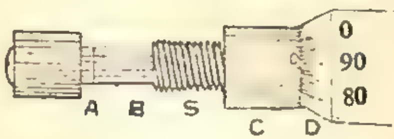


Fig. 22

scale leads or lags, exactly like that of vernier scale. In Fig. 21, the circular scale reading is 12, while the studs are in contact. So the instrumental error is 12. But in Fig 22, the circular scale reading is 87 while the studs are in contact. So it lags by 13 divisions in respect 0·0 coincidence of the scales. If the least count of the instrument is ·01 cm. then the instrumental error or what is commonly called the zero error is $-·13$ cm.

Back-lash Error—This is an error characteristic of a micrometer screw. Within every nut there is a little space for the play of the screw. With a continued use the screw and the nut wear away gradually due to friction and this space increases more and more. The result is that when the screw is turned continuously in one direction, the stud at the end of the screw moves as usual; but when from some point the screw is rotated in opposite direction, the stud does not move for a while. The error introduced on reversing the direction of turning is called the *Back-lash* error. This error is avoided if the micrometer screw *before taking any reading*, is always turned in the same direction. With new instruments this error is minimum.

Date—

EXPERIMENT 5

To Measure the Diameter of a piece of Wire with a Screw Gauge and hence to find its average Cross-section

Theory—The least count of a screw gauge is equal to the pitch of the screw divided by the number of divisions on the circular scale. The thickness of an object just fitting between the studs is given by the actual reading of the instrument plus or minus the instrumental error as the case may be.

Apparatus—A screw gauge and two samples of wire (No. 22 and No. 26 S.W.G. say).

[Here a description of a screw gauge is necessary and a diagram of it is to be drawn on the blank page.]

Procedure—Find the value of the smallest division of the linear scale with reference to a metre scale. Bring the edge of the collar

carrying the circular scale on any graduation of the linear scale, and give the micrometer screw *a complete turn* and note the distance through which the edge moves. This distance gives the pitch of the screw. Then count the number of divisions on the circular scale. Thus, dividing the pitch by the number of divisions on the circular scale, obtain the least count of the instrument. (*Vide* pp. 34.)

To determine the instrumental error, turn the screw head so that the studs are just in contact and take the reading of the circular scale against the reference line of the linear scale. Take three such readings as shown in table 1, p. 35 and calculate mean value.

If the zero of circular scale is now against the zero of the linear scale, there is no instrumental error. If the edge of the collar is in advance of the zero of the linear scale the instrumental errors is positive. If, on the other hand, the edge of the collar is behind zero, the instrumental error is negative.

Then open out the studs sufficiently and introduce the wire under measurement breadthwise into the space so made. Slowly turn the screw by the friction clutch *in one direction* so that the studs gently press the wire at opposite ends of a diameter. Take reading of the last visible division of the linear scale and the circular scale which is opposite the base line. At each region of the wire take two readings perpendicular to each other. One is called the direct reading (D) and the other the crossed reading (C). Take three or four pairs of such readings at different parts of a wire specimen and enter observations as shown in Table 2, p. 36.

Find the mean value of the readings obtained and add or subtract the instrumental error to this mean, as the case may be. The final result gives the required diameter.

Results :—

The smallest division on the linear scale = 0·1 cm. say.

Pitch of the micrometer screw = 0·1 cm.

Number of divisions on the circular scale = 100.

$\therefore$ Least count of the micrometer $= \dfrac{0{\cdot}1}{100} = 0{\cdot}001$ cm.

1. Determination of instrumental error :—

Position of Collar	No. of readings	Main scale cm.	Circular scale	Fractional part cm.	Total cm.	Mean cm.	Instrumental error cm.
Behind linear zero	1.	0	99	.099	0·099		·1 − ·099
	2.	0	99	.099	0·099		
	3.	0	99	·099	0·099	0·099	= ·001
	4.	0	98	·098	0·098		
	5.	0	99	·099	0·099		

2. Determination of the diameters of two samples of wire [(1) No. 22 S.W.G. wire and (2) No 26 S.W.G. wire.]

Body	Reading No. of	Linear Scale	Circular Scale	Fractional part	Total	Mean	Instrumental error	Corrected Diameter cm.
		cm.		cm.	cm.	cm.	cm.	
No. 22 S.W.G. Wire	1D	0	70	0·070	0·070	0·0704	+0·001	·0714
	C	0	71	0·071	0·071			
	2D	0	71	0·071	0·071			
	C	0	71	0·071	0·071			
	3D	0	70	0·070	0·070			
	C	0	70	0·070	0·070			
No. 26 S.W.G. Wire	1D	0	45	0·045	0·045	0·0455	+0·001	·0445
	C	0	45	0·045	0·045			
	2D	0	45	0·045	0·045			
	C	0	46	0·046	0·046			
	3D	0	46	0·046	0·046			
	C	0	46	0·044	0·044			

$$\text{Radius of 1st wire} = \frac{·0714}{2} = ·0357 \text{ cm.}$$

$$\text{Radius of 2nd wire} = \frac{·0454}{2} = ·0227 \text{ cm.}$$

Hence the average cross-section of No. 22 S. W. G. wire $= 3·14 \times ·0357^2 = 0·004$ sq. cm. and that of No. 26 S. W. G. wire $= 3·14 \times ·0227^2 = 0·0016$ sq. cm.*

Discussions—The actual diameter of No. 22 S. W. G. wire as obtained from the Table of Constants is 0·0711 cm. and the measured diameter is 0·0714 cm. The percentage of error is therefore 0·6%. For the other specimen the actual diameter is 0·0457 cm. while the observed one is 0·0445 cm., the percentage of error being 0·26%.

The back-lash error has always been avoided by turning the screw inwards. Since the least count of the instrument used is 0·001 cm., we can expect to have accuracy upto the third place of decimals, although the fourth place has been obtained from a calculation of the mean value. A greater accuracy could have been attained by using a screw gauge having a pitch of 0·5 mm. and a circular scale containing 100 divisions. In that case the least count would have been 0·0005 cm. and we would have obtained a result correct upto the fourth place of decimals directly.

*A typical calculation by using log table is shown here. All calculations should be shown on the left side page of the fair Table Note Book.

Let $3·14 \times ·0357^2 = x$. Then $\log_{10} (3·14 \times ·0357^2) = \log_{10} x$
or $\log_{10} 3·14 + 2 \log_{10} ·0357 = \log_{10} x$

From Log Table, $\log 3·14 = 0·4969$ $\therefore \log x = \bar{3}·6023$
$\log ·0357 = \bar{2}·5527$ or, $x = \text{antilog } \bar{3}·6023$
$\log ·0357 = \bar{2}·5527$ $= ·004001$ sq. cm.
By addition $\bar{3}·6023$ (Found from Antilog Table)

EXERCISES

1. Find the mean external and internal diameters of the given copper calorimeter with the vernier callipers.
2. Find the volume of the given cylinder with the vernier callipers.
3. Find the average thickness of a glass piece with the screw gauge.
4. Find the average cross-section of the given wire with the screw gauge.
5. Measure the diameter of the given ball with the slide callipers

Spherometer—A spherometer is used for the measurement of small thickness of plates and also for the determination of the radius of curvature of a spherical surface. It works on a similar principle as that of a micrometer screw gauge.

It consists of a frame-work supported on three legs A, B and C of equal length (Fig. 23). The legs have pointed ends and are equidistant from one another. In a nut at the centre of the frame a fine screw having a pointed end E works forming an adjustable central leg. There is a round graduated disc D at the upper end of the screw and it is fixed rigidly with the milled head M. A small scale S is fixed vertically at one end of the frame very close to the disc and is usually graduated in millimetres.

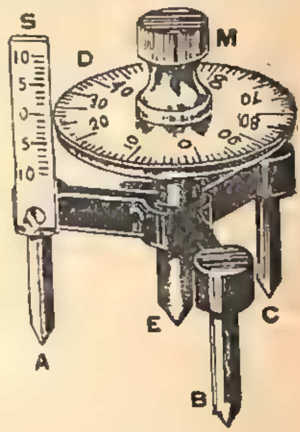


Fig. 23

In a carefully designed instrument the zero line of the main scale and zero of the circular scale should coincide when all the legs, including the central one, just touch a plane surface. But with use, this adjustment is lost and the edge of the disc is below or in advance of main scale zero when the four legs stand on the same plane involving a positive or negative instrumental error. The algebraic sign of this error depends upon the direction in which a subsequent measurement is to be made.

Date— EXPERIMENT 6

To determine the Thickness of a Plate Glass with a Spherometer

Theory—The thickness of plate is equal to the difference of the readings of the spherometer when its central leg first touches the upper surface of the plate and then the plane sheet on which other legs rest.

The least count of the spherometer is equal to the pitch of the central leg divided by the total number of divisions on the circular disc.

Apparatus—A spherometer, a piece of plane glass (base plate), and a thin plate glass (test plate).

Procedure—Determine the value of the smallest division of the vertical scale attached to the frame of the spherometer with the help of an auxiliary scale. This value is generally 1 mm. or ·5 mm.

Rotate the screw by its milled head for a complete turn and observe how far the disc advances or recedes with respect to the vertical scale attached. This distance gives the pitch of the instrument. Then count the total number of divisions on the circular scale. The number of divisions on the circular scale is generally 100 or 50. Then the pitch divided by the number of divisions on the circular scale gives the least count of the instrument. Recheck your findings before entering your data.

Place the spherometer upon a plane glass piece usually called the base plate, and slowly turn the milled head so that the tip of central leg *just touches* the surface of the glass (Fig. 23). When the screw head just touches the base plate, then on looking obliquely at the plate against a bright back ground, the screw head and its image by reflection at the plate would appear to touch each other. On *slightly* moving the screw in the same direction, the spherometer legs would be found to develop a tendency to *slip over the plate.* This is the position when the tips of all the legs and that of central screw are touching the plane of the plate.* Now, take the reading of the main scale nearest the edge of the disc. Take also the reading of the circular head against the linear scale and tabulate the results as shown below. Take five such readings for different positions of the instrument on the base plate. The product of the circular scale reading and the least count gives the fractional part. The main scale reading plus the fractional part gives the total reading. Take a set of five readings and obtain the mean value.

Next, with the spherometer on the base plate raise up the central screw and introduce the glass plate whose thickness is to be measured between the base plate and the screw. Turn the screw head again till it just touches the plate, the position of contact being examined as previously. Take the readings of the linear and circular head. Move up the central screw and *slightly* shift the position of the test plate and take readings for the thickness of the test plate at this position. Take a third set of readings for another position of the plate. Turn the plate upside down and take three such readings in a similar way. Finally, calculate the mean value. The difference of the two mean values gives the average thickness of the plate.

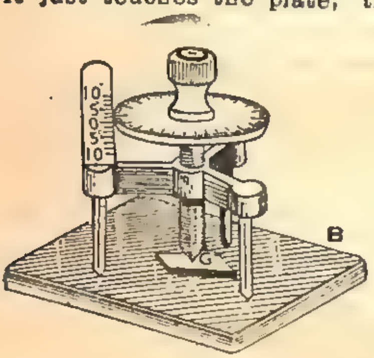


Fig. 24

[If the spherometer is old, the plane of the disc slightly oscillates as it rotates. In that case, it is not proper to take the linear scale reading as this involves

*The exact setting of the central leg requires some practice and experience. If the central leg has been turned down too much, the frame of the spherometer would be found rocking and spinning about the central leg when the screw head is touched. In such a case the central leg should be raised up by one or two revolutions and is then again turned down until the slipping of other legs just commences.

a serious error in the reading of the linear scale. It is proper then to count only the total number of circular divisions passed through from the initial to the final stage. This is explained fully in the following lines.]

Results—

The main scale is graduated in millimetres (suppose).
Pitch of the micrometer screw = 0·5 mm. = 0·05 cm.
Number of divisions on the circular scale = 100.

$$\therefore \text{ Least count of the instrument} = \frac{0·05}{100} = 0·0005 \text{ cm.}$$

Readings on	No. of Readings	Linear Scale	Circular Scale	Fractional part	Total reading	Mean
		cm.		cm.	cm.	cm.
Base plate	1.	0	− 3	−0·0015	−0·0015	−0·001
	2.	0	− 2	−0·0010	−0·0010	
	3.	0	− 3	−0·0015	−0·0015	
	4.	0	− 1	−0·0005	−0·0005	
	5.	0	0	0·0000	0·0000	
The plate glass	1.	0·2	15	0·0075	0·2075	·2058
	2.	0·2	18	0·0090	0·2090	
	3.	0·2	20	0·010	0·2010	
turned upside down	1.	0·2	18	0·0090	0·2090	0·2065
	2.	0·2	19	0·0095	0·2095	
	3.	0·2	20	0·010	0·2010	

Discussion—The mean of the micrometer scale readings on the plate glass is found to be 19 and the minimum reading is 15. This makes the maximum variation of 4 circular scale divisions which is equivalent to a linear movement of the screw through $4 \times 0·0005 = 0·002$ cm. Thus the maximum error in reading a thickness of 0·2062 cm. might have been 0·002 cm. which means a percentage error of 1·0%.

Care must be taken to see that the central screw just touches the plate. The screw must not be turned down any further when once the spherometer begins to swing.

Oral Questions

What are meant by the pitch of a screw and the least count of a screw gauge? What is an instrumental error and how to find it? Explain a back-lash error and the method of avoiding it. Why is the instrument called spherometer?

How do you check that all the four legs have stood on the plate? You are provided with two spherometers having an equal least count; but pitch of one screw is 1 m m while that of the other is 0·5 mm.; which would you prefer for a more accurate measurement?

Alternative Method of Measurement of Thickness—With a continued use, the parts of a spherometer wear out and are thrown out of adjustment. For example, it may happen that when the zero of the circular scale comes against the linear scale,

the edge of the circular scale may not coincide with any scale division ; or when giving a complete rotation of the disc, the edge of the disc may oscillate up and down the linear scale graduation. It is then a matter of difficulty and confusion to take the reading of the linear scale.

For circular heads having very little adjustment with the linear scale the following method proves very convenient. Find the pitch of the central screw by giving it a few complete turns and as usual calculate the least count of the spherometer. Now place the spherometer on the base plate and raise the central leg sufficiently. Then place the plate under the central leg and screw it down so that it touches the base plate, the state of contact is always to be judged by the slight swinging of the spherometer. Then note the division of the circular scale against the linear scale. Now take away the plate without removing the relative position of the spherometer and the base plate and screw down the central leg slowly. Count the number of rotations of the circular head, till the central screw touches the base plate. The total count may be done by two instalments—by the number of the complete revolutions of the disc and the difference of initial and final disc readings. These two are added together in proper units to get the true reading. For example, suppose that there have been 3 full rotations and the fractional part is 45 divisions If the pitch of the screw is 0·5 mm. and least count is 0·005 mm, then the thickness of the plate is $3 \times {\cdot}5 + 45 \times {\cdot}005$ mm. $= 1{\cdot}5 + {\cdot}225$ mm. $= 1{\cdot}725$ mm. Ofcourse one reading is not always sufficient and a number of readings are to be taken. It is always advisable for students to practice both the methods with a spherometer.

The Tabulation of Results should be done in the following way.

Pitch = 0·5 mm. Least Count = 0 005 mm (say).

No. of readines	No. of complelo revolution	Revolutions equivalent to mm.	Initial	Final	Difference	Least count mm.	L, C. × Disc Reading	Actual Reading mm.
1.	3	1·5	32	80	48	·005	0·23	1·740
2,								
3.	3	1·5	...	81	49	·005	0.245	1·733
4.								
5.	3	1·5	..	8[illegible]	..	·005	0·2[illegible]5	1.738

For measurement of depth, difference = initial − final. For height, difference = final − initial.

Theory of Measurement of the Radius of Curvature—This instrument may also be used to measure the radius of curvature of a spherical surface : hence the name spherometer. The following is the method of procedure. The reading of the spherometer is

taken as usual on a plane sheet of glass. Let the mean reading be s.

Then the central screw is raised up, if necessary, and the spherometer is placed on the spherical surface such that the fixed legs are all on this surface. Then the screw is turned down slowly as to touch the spherical surface. In Fig. 25, A, B and C are the ends of the fixed legs of the spherometer on the spherical convex surface and E the central leg just touching the surface. At this position the reading of the spherometer is taken. Five such readings are taken at different positions of the surface and the mean is found. Let the mean reading be b and suppose that $b-s=h$.

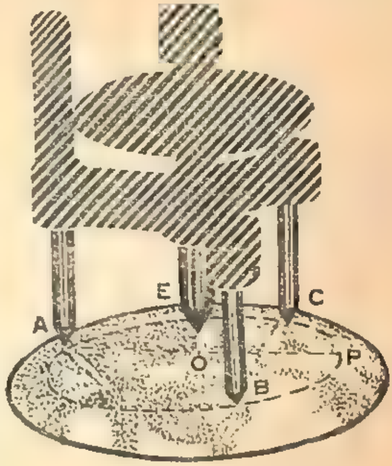


Fig. 25

Next the central screw is raised up, if necessary, and the spherometer is placed on a piece of white paper and is slightly pressed. Three dots corresponding to the ends of the fixed legs are imprinted on the paper. The distances between the dots are separately measured with a pair of dividers and metre scale or with a diagonal scale and the mean value is calculated. Let it be c. Then the radius of curvature R of the spherical surface is given by,—

$$R = \frac{c^2}{6h} + \frac{h}{2}$$

To prove the above relation, imagine a plane to pass through the points A, B and C on the spherical surface. This plane cuts the surface in a circular section ABPC of which the point O is the centre (Fig. 26). The point O is obtained by producing direction of the middle leg E so as to cut the plane ABPC. Draw a diameter AOP of the circle.

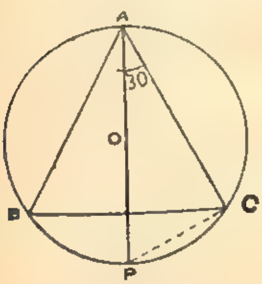


Fig. 26

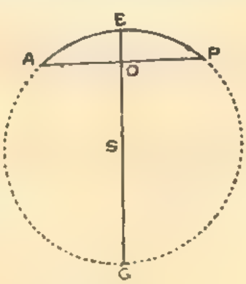


Fig. 27

Imagine another vertical circle to pass through the points A, E and P on the spherical surface (Fig. 27). The radius of this circle is evidently the radius of curvature of the spherical surface. The middle leg of the spherometer moves at right angles to the plane ABC which passes through the tips of the fixed legs. Since the line AOP lies in this plane, the line EO which gives the direction of motion of the middle leg is perpendicular to it. Thus

the line EO measures the depth of the plane ABPC below the point E and is equal to the difference of readings h of the spherometer on the spherical surface and the plane surface.

Since O is the centre and AP is the diameter of the circle ABPC (Fig. 26), O is the middle point of AP. Again the circle AEPG (Fig. 27), in which AP becomes the chord and is bisected at its middle point O by a line EO at right angles, EO if produced passes through the centre S and meets the circumference at a point G. Thus EG is the diameter of the circle AEPG. If the radius ES of the circle be R, then

$$EO \times OG = AO \times OP, \text{ that is, } EO \times (EG - EO) = AO \times OP$$

$$\therefore \quad h\,(2R - h) = AO^2$$

$$\text{whence} \quad R = \frac{AO^2}{2h} + \frac{h}{2}$$

Fig. 26 represents the circle ABPC, on which the points A, B and C correspond to the tips of the fixed legs of the spherometer on the circumference and AOP is the diameter. Since the fixed legs are equidistant, the triangle ABC is equilateral and each angle of this triangle is equal to 60°. Further, arc ACP = ABP and also arc AB = arc AC standing on equal chords. Therefore arc PC = arc PB and hence $\angle PAC = \angle PAB = 30°$

$$\text{Now, } AC = AP \cos 30°$$

$$= 2AO \cos 30°$$

$$\therefore \quad AO = \frac{AC}{2 \cos 30°} = \frac{AC}{\sqrt{3}} = \frac{c}{\sqrt{3}}$$

$$\text{Finally, } \quad R = \frac{AO^2}{2h} + \frac{h}{2} = \frac{c^2}{6h} + \frac{h}{2}$$

Date—

Experiment 7

To Measure the Radius of Curvature of a Spherical Surface with a Spherometer

Theory—The radius of curvature R of a spherical surface is given by the equation

$$R = \frac{c^2}{6h} + \frac{h}{2}$$

where c = the mean distance between the fixed legs.

and h = the difference of the spherometer readings on the spherical and the plane surfaces.

Apparatus—A spherometer, a convex lens, a metre scale and a piece of white paper.

(A brief description of a spherometer is necessary and a diagram as that of Fig. 24 is to be drawn on the blank page.)

Procedure—Find the pitch and the least count of the spherometer (*vide* Expt. 6). Place the spherometer on a piece of plane

glass (base plate) and take the reading of the instrument when the central leg touches the plate (follow the instructions for this procedure as given on p. 38). Take five readings on different parts of the base plate. The mean of the readings represents the reading on the plane surface. Let it be b.

Next raise the central screw and place the spherometer on the convex surface. Turn the screw down slowly till it touches the surface, when a small swing of the instrument is noticed. Take the readings of the linear and circular scales at this position. Place the spherometer at five different positions on the spherical surface and take the reading of the instrument each time when the central leg touches the surface. The mean of these readings represents the reading on the spherical surface. Let it be a. The difference of a and b represents h.

Now place the spherometer upon a piece of paper and slightly press it so as to leave three dots on the paper corresponding to the fixed legs. Measure the distance AB, BC and CA separately with a vernier scale avoiding parallax and applying eye estimation or with a divider and a metre scale. The mean of the distances represents c. Finally, with the help of the formula already proved, calculate the radius of curvature of the spherical surface.

Results—

The pitch of the micrometer screw = 0·5 mm. = 0·05 cm. (say).
Main scale graduated in millimetres (suppose).
Number of divisions on the circular scale = 100

$\therefore$ The least count of the instrument $= \dfrac{0\cdot05}{100} = 0\cdot0005$ cm.

The distance AB between the legs = 3·15 cm.
The distance BC between the legs = 3·25 cm.
The distance CA between the legs = 3·20 cm.
$\therefore$ Mean distance between the legs = 3·20 cm.
Spherometer Readings—(A typical set of readings is given).

Readings on	No. of Readings	Linear Scale	Circular Scale	Fractional part	Total	Mean
		cm.		cm.	cm.	cm.
Glass Plate	1.	0	11	0·0055	0·0055	0·0055 = a
	2.	0	9	0·0045	0·0045	
	3.	0	12	0·0060	0·0060	
	4.	0	10	0·0050	0·0050	
	5.	0	13	0·0065	0·0065	
Spherical Convex surface	1.	0·15	67	0·0335	0·1835	0·1821 = b
	2.	0·15	66	0·0330	0·1830	
	3.	0·15	60	0·0300	0·1800	
	4.	0·15	61	0·0305	0·1805	
	5.	0·15	65	0·0335	0·1835	

$\therefore \quad h = b - a = 0{\cdot}1831 - 0{\cdot}0055 = 0{\cdot}1766$ cm.

Hence $R = \frac{c^2}{6h} + \frac{h}{2} = \frac{3{\cdot}20^2}{6 \times 0{\cdot}1766} + \frac{0{\cdot}1766}{2} = 9{\cdot}75$ cm.

Discussion—In the above experiment although the spherometer records readings upto the 4th place of decimals, the mean distance between the legs could be measured approximately upto the 2nd place. Hence it is of no use to push the result to more than 2 places of decimals.

The mean distance between the legs should be measured accurately. Since this term occurs as a square, any small error in its measurement will be magnified in the result. Hence, in some cases, this distance is measured with a microscope having vernier attachment. In the determination of R the quantity $h/2$ may be often neglected as compared to $c^2/6h$.

Assuming that the maximum variation of reading of c could not have been more than 0·05 cm. in a mean value of 3·20 cm and also the variation in h is 0·0015 cm. in a mean value of 0·1766 cm.; the percentage of error in calculating R is very nearly 2·3%.

Oral Questions

How can a spherometer be used to measure the radius of curvature of a surface? Can it be used to measure the radius of curvature of cylindrical surface? If not, why? What is the order of radius of curvature of a surface you can expect to measure with a spherometer whose least count is 0·001 cm.? What precautions are you to take in measuring the radius of curvature of a surface?

How can you justify the statement that a more accurate reading is possible with a spherometer with its central leg being of a shorter pitch? Is it possible to measure the radius of curvature of a surface with a spherometer whose middle leg does not pass through the centroid of the other three legs? If not, why? Is the reading of a spherometer affected by a change of temperature?

Exercises

1. Measure the internal and external radii of curvatures of the given watch glass with the spherometer supplied.
2. Measure the radii of curvatures of the given convex lens as also the diameter of the aperture of the lens. Hence determine the thickness of the lens.
3. Measure the density of the material of a brass ball from a knowledge of its mass and radius of curvature.

Graphical Representations and their Uses

When two quantities depend upon each other in such a way that a change in one produces a corresponding change in the other, they are called *variables*. In the world around us we come across very many variable quantities. For example, it is well known that the *volume* of any substance changes with its *temperature*. Here volume and temperature depend upon each other; consequently any change in the temperature of the substance produces a corresponding change in its volume. Again, when a body is thrown vertically upwards against gravity, its velocity gradually decreases with height. Thus velocity and height depend upon each other and are therefore variables. Of a pair of variable quantities one can be *directly*

controlled by experimental conditions and it is called the *independent* variable. The other quantity, which undergoes a consequent change as an effect, is called the *dependent* variable.

The relative variation of the two variable quantities can be conveniently studied on a graph paper in the following way. For any particular value of the independent variable there would be a corresponding value of the dependent variable. The two values form a pair and are called the *co ordinates* of a point on the graph paper. For example, suppose that we have obtained a variation of atmospheric temperature of two localities with different hours of a day, as supplied by the following charts.

Date— 10th January, 1954

Time—Temperature Chart

At Calcutta				At Lahore			
Hours A.M.	Temp. 0°F	Hours P.M.	Temp. 0°F	Hours A.M.	Temp. 0°F	Hours P.M.	Temp. 0°F
0	50	2	74	0	47	2	86
2	49	4	69	2	43	4	78
4	48	6	65	4	42	6	68
6	50	8	60	6	43	8	59
8	55	10	55	8	46	10	53
10	58	12	51	10	57	12	47
12	65	—	—	12	70	—	—

Selection of Axes of Co-ordinates—A squared graph paper is now taken, which consists of two sets of equidistant lines cutting each other at right angles (Fig. 28). The point of intersection of any horizontal line and a vertical line may be taken as the origin of co-ordinates and those two intersecting lines are then called two *axes* of co-ordinates. The point O at the centre of the squared paper may be taken as origin. The horizontal axis XX′ is called the *abscissa* and the vertical one YY′ the *ordinate*. The two intersecting axes of co-ordinates divide the graph paper into *four* chambers or quadrants. If from the origin we go towards the right hand side, it would indicate a positive direction of abscissa; a vertically upward direction along the ordinate will give positive value of this co ordinate. Conversely the left hand direction from the origin along the abscissa or the vertically downward direction along the ordinate from the origin would mark the negative values of corresponding co-ordinates.

There is no hard and fast rule regarding the choice of the origin on the graph paper. The position of the origin on the graph paper may be any point such as O_1, O_2, O_3 etc. according to the units and limiting values of the co-ordinates. If the limits of co-ordinates of both the variables x and y extend from positive to negative values the origin is to be located somewhere at the middle part of the graph paper. If the variables have positive values only, the origin may be conveniently put at O_4 the left bottom corner of the paper.

Selection of Units—After fixing up the position of the origin, units of measurement along the axes should be chosen properly. It is customary to measure the independent variable along the abscissa and dependent variable along the ordinate. As a bigger graphical representation shows a greater detail of the relation, it should always be the look out of a student *to utilise as much of the squared paper as possible* to draw the graph. Unless required for some special reason the intersection of the axes may not be taken as

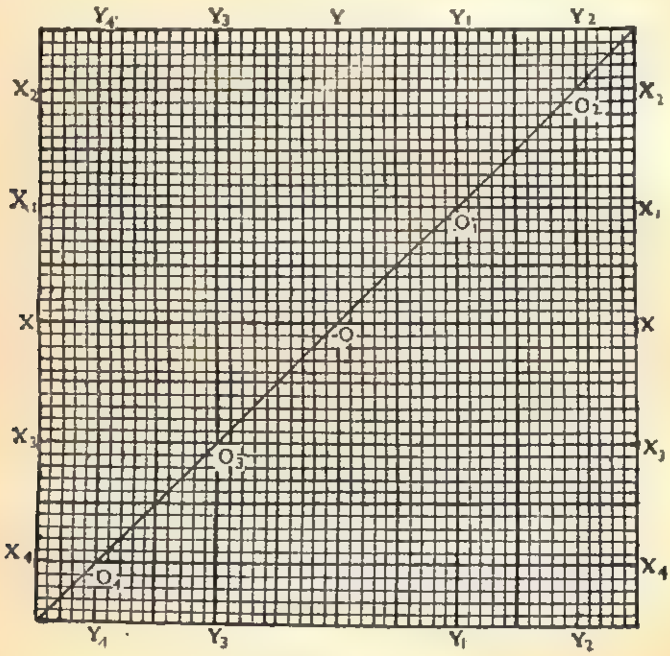


Fig. 28—A Squared Paper

the zero value of the variables. We may put any arbitrary values of the co-ordinates at the origin. For example, suppose that we are required to draw the graph of the independent variable between the limits + a and + b and the dependent variable between the limits + c and + d. To do this, if the units on the two axes are chosen in such a way that almost the total length of the abscissa contains values from a to b and the ordinate from c to d, the whole of the squared paper would be utilised. In the particular illustration the values of hours of the day, taken as the independent variable along x axis, are found to vary within the limits 0 A.M. to 12 P.M. Hence the units on the abscissa are so chosen as to contain values from 0 to 12 in 2 parts. Similarly as temperature changes from 42°F to 86°F the ordinate is graduated to contain values from 40 to 90. Thus the curve covers almost the whole of the graph paper.

Plotting of Points—Each point obtained on the graph paper is represented by either a small cross (×) or a small circle (O). In

the particular illustration the hour-temperature points of Calcutta are identified by small circles and those of Lahore by crosses.

Drawing the Curve—Finally when all the points have been plotted on the graph paper, freehand *smooth* curve is drawn through the points. This process is technically known as **smoothing the curve.** If a smooth curve cannot be drawn satisfying all the points, then an even curve should be drawn, so that a few points lie on either side of the curve.

One or two points may be found to lie at a *considerable* distance from the graph so drawn. These points arise out of spurious errors in observation and may be left out of consideration. A typical freehand smooth curve is shown in Fig. 29, in which one spurious observation is recorded.

In drawing a precision type of a graph from experimental observations, the probable percentage of error of such a set of observations is calculated previously. Each reading on the graph paper is represented by a short line with its centre coinciding with the actual observation. The length of each line gives a probable variation of the reading. Finally a smooth curve is made to pass through the system of short lines (vide *appendix* at the end of the book).

Study of Graph—A graphical representation offers a ready method of studying the relation between the two variable quantities. When the graph exhibits a straight line *parallel* to any co-ordinate axis, it shows that any change in the variable, measured along that axis, does not affect the quantity measured along the other axis. If on the other hand the graph shows a straight line inclined to both the axes, it indicates that the relationship between variables is linear and any regular changes of one variable produce uniform changes of the other. In general, when the nature of the graph is a regular curve, namely a circle, a parabola, a hyperbola or an ellipse, it is possible to find *directly* the equation to the curve. The graph between two variables is in a few cases irregular in which case the mathematical relation may be found by a method of computation.

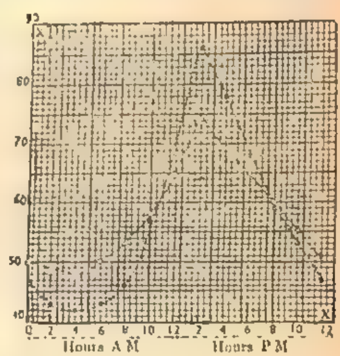


Fig. 29—To draw a graph

In the particular illustration of the graph, it is noticed at a glance that the temperature variation curve at Lahore (chain curve) is more steepy and rises to a higher peak from a deeper level. Hence it may be inferred that climatic condition there is more extreme than that of Calcutta.

Exercises

1. Draw a graph with the following data showing the relation between the Centigrade and Fahrenheit scales and hence show the Centigrade reading corresponding to the normal human temperature of 98·4°F.

Fahrenheit temperatures	80·00	85·00	90 00	95·00	100·00	105·00	110 0
Centigrade temperatures	26·66	29·44	32·22	35 00	37·77	40·55	43·33

2. Draw a graph showing the relation between the density of water in gram per cubic centimetre and centigrade temperature with the following data and hence find the temperature at which the density becomes 0·999950 gm. per c.c.

Temp. in°C	Density in gram per c.c.	Temp. in°C	Density in gram per c.c.	Temp. in°C	Density gram per c.c.
0 1 2	0·999841 0·999302 0·999941	3 4 5	0·999955 0·999973 0 999965	6 7 8	0·999941 0·999302 0·999840

3. Draw a graph of $x=\sin\ \theta$ between the limits 0° and 180° from the following data :

t°	x	θ°	x	θ°	x	θ°	x
0 20 30 40	0·00 0·34 0·50 0·64	50 60 70 80	0·76 0·86 0·94 0·98	90 100 110 120	1·00 0·98 0·94 0·86	130 145 160 180	0·76 0·57 0 34 0·00

4. Show graphically that,

(i) $y^2=4x$ represents a parabola

(ii) $xy=81$ represents a hyperbola.

Measurement of Angle

The idea of an angle is derived from an attempt to represent rotational motion of bodies. Let a body of any arbitary shape be revolving on the plane of the paper about an axis O in an anticlockwise direction. (Fig. 30) Let it occupy the position given by the solid line at any instant of time and let any straight line AB be drawn upon it to pass through O. As the body rotates, the line also rotates through the point O in the same direction. Let the line occupy the position OD after a given interval.

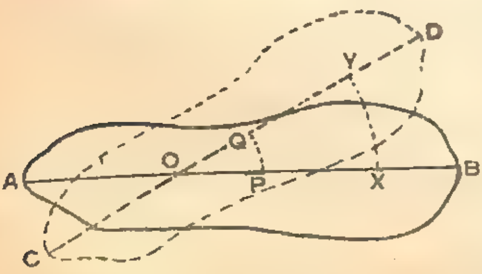


Fig. 30—Rotation of a Body

A point P on the line AB at the end of the interval occupies the position Q by tracing out a circular arc PQ and similarly another point X traces an arc XY in the same interval. Similarly all other points of the body would move over circular arcs with the point O as the centre. It is found by actual measurement that,

$$\frac{\text{arc } PQ}{PO}=\frac{\text{arc } XY}{XO}$$

This ratio is constant for every point of the body and is, therefore, a measure of the amount of rotation of the body at this particular instant. The ratio of an arc to the corresponding radius is called an angle in circular measure. Thus, the rotational motion is expressed by the angle turned through by the body during some particular interval.

The unit of angle on this measure is called a **radian** and is defined to be the angle subtended at the centre by a circular arc of length equal to the radius. The time for every complete revolution of the body is called its *period*. It is a fact that the circumference of a circle stands a constant relation π with its diameter.

Now, $$\frac{\text{circumference}}{\text{diameter}}=\pi=3{\cdot}1415......$$

or, $$\frac{\text{circumference}}{\text{radius}}=2\pi \quad \therefore \quad \text{circumference}=2\pi\times\text{radius}.$$

The number of radians for a complete revolution

$$=\frac{\text{length of the circumference}}{\text{radius}}=2\pi=6{\cdot}2830......$$

The value of π cannot be expressed as an exact fraction but it can only be expressed correct to some definite places of decimals. To express an angle in term of a radian, a circular arc is drawn with the apex of the angle as centre. Next the length of the arc subtending the angle is measured accurately. Then the angle expressed in radians is given by the quantity,

$$\frac{\text{length of the arc}}{\text{length of the radius}}$$

Another more convenient unit of angle is chosen by dividing the circumference of a circle into 360 equal parts. The angle at the centre subtended by any one of the arcs is called a **degree**. The angle subtended at the centre by a semi-circle contains 180 degrees and that by one quarter of a circle contains 90 degrees, called a right angle. The multiple and submultiples of a degree are the following :—

1 Right Angle = 90 degrees (90°)
1 degree (1°) = 60 minutes ($60'$)
1 minute ($1'$) = 60 seconds ($60''$)

Since a semi-circle subtends an angle of π radians as also 180° at the centre,

$$\pi \text{ radians}=\pi^c=180^\circ$$

$$\therefore \quad 1 \text{ radian}=\frac{180^\circ}{\pi}=\frac{180^\circ}{3{\cdot}1415}=57^\circ\ 17'\ 44{\cdot}8''$$

Examples

1. Express 30° in terms of radians.

A. Since $180° = \pi^c$, $1° = \frac{\pi^c}{180}$

$$30° = \frac{30}{180}\pi^c = \frac{1}{6}\pi^c = \frac{3.1415}{6} \text{ radian} = 0.523 \text{ radian.}$$

2. An angular vernier can read upto half a minute. What is its vernier constant in radian ?

A. Since $180° = \pi^c$, $1° = \frac{\pi^c}{180}$ and $1' = \frac{\pi^c}{180 \times 60}$

$$\therefore \quad 0.5' = \frac{\pi^c}{180 \times 60 \times 2} = \frac{3.1415}{21600} \text{ radian} = 1.45 \times 10^{-4} \text{ radian}$$

3. A railway locomotive is provided with two sets of wheels of diameters 5 ft. and 2 ft. respectively. Calculate the number of revolutions each type of the wheel will make in covering a distance of 10 miles.

A. The diameter of bigger wheel = 5 ft., hence its radius = 2.5 ft.

Distance moved for 1 revolution = circumference of the wheel = $2\pi \times 2.5$ ft.

$$\therefore \quad \text{No. of revolutions for 10 miles} = \frac{10 \times 1760 \times 3}{3.1415 \times 5} = 3364.1$$

In a similar way, it can be shown that for the smaller wheel,

$$\text{no. of revolutions for 10 miles} = \frac{10 \times 1760 \times 3}{3.1415 \times 2} = 8410.3$$

4. A fly wheel of diameter 1 metre revolves 200 times per minute. Calculate the linear velocity of a point on the rim of the fly wheel.

A. A revolution of 200 per min. $= \frac{200}{60}$ per sec. One revolution of the wheel $= 360°$ rotation of any point about the centre $= 2\pi$ radian rotation.

$\therefore$ Angular velocity of the wheel $= \frac{200}{60} \times 2\pi^c = \frac{20}{3}\pi^c$

Hence linear velocity of any point on the rim

$=$ angular velocity $\times$ radius $= \frac{20}{3}\pi \times 50$ cm./sec.

$= \frac{1000 \times 3.1415}{3}$ cm./sec. $= 1047.16$ cm./sec.

Protractor—This apparatus is used for the measurement or construction of an angle in degrees. It consists of a semi-circular piece of metal divided on its circumference into 180 equal parts, each called a degree (Fig. 31). The scale is graduated both ways. The lower straight edge of the piece forms the diameter of the semi-circle having the centre at O. Protractors supplied in ordinary mathematical instrument box are generally graduated with divisions of full degrees. There are more precision types of protractors having $\frac{1}{2}$ or $\frac{1}{3}$ degree as the smallest graduation.

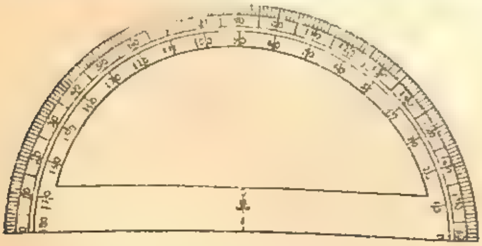


Fig. 31—Protractor

Date— EXPERIMENT 8

To measure and construct Angles with a Protractor

Theory—If the reading of one straight line on the semi-circular scale of a protractor be $x°$ and of other straight line be $y°$, then the angle between the lines is $x \sim y°$, provided that the apex of the angle be made coincident with the centre of the semi-circular scale.

Apparatus—A protractor, a metre scale and drawing requisites.

[A description of a protractor is to be given here and a sketch of it is to be drawn on the blank page.]

Experimental Procedure—Draw two straight lines with a metre scale at any arbitrary angle on the drawing paper with fine pencil point. Place the protractor with its centre coincident with the apex of the angle. Read the ends of the lines emerging out of the curved edge in degrees avoiding parallax and applying eye-estimation. Take at least three pairs of readings for each angle at different parts of the scale. The difference of readings of each pair of straight lines gives the angle between the lines. Finally, calculate the mean value of angles, which gives the required angle between the straight lines. The eye-estimation of a fraction of a degree may be made more conveniently with a reading (magnifying) glass.

In order to construct a given angle, place the protractor flat on the drawing paper and draw line along the straight edge. Put a pencil dot at the centre O as accurately as possible. Observe the circular edge and mark another pencil dot against the reading of the scale giving the angle to be constructed. Then remove the protractor and join the two dots by a straight line with a metre scale. The angle is thus constructed. The accuracy with which an angle may be constructed depends upon the type of the protractor supplied and the accuracy with which the pencil dot may be put.

Results—

Angle between	No. of observations	Inner scale: End of one line	Inner scale: End of other line	Difference of readings	Outer scale: End of one line	Outer scale: End of other line	Difference of readings	Mean
		deg.	deg.	deg.	deg.	deg.	deg.	deg.
1st pair of lines	1	0	39·5	39·5	0	39·4	39·4	39·5
	2	20	59·4	39·4	15	54·5	39·5	
	3	70	109·5	39·5	40	79·5	39·5	
2nd pair of lines	1	50	125·5	75·5	0	75·3	75·3	75·4
	2	70	145·4	75·4	10	85·5	75·5	
	3	80	155·4	75·5	28·5	104	75·5	
3rd pair of lines	1	0	123	123	0	123	123	123
	2	15	138	123	16	139·2	123·2	
	3	30	153·2	123·2	30	153	123	

Discussions—The eye estimation may be applied with a protractor correct to about 0·2°. Assuming that the maximum variation from the correct value might be ± 0·2°, the percentage of error in reading 39·5° is 0·5%, 75·4° is 0·3% and 123·2° is 0·2%. Thus it is found that the larger is the angle, the less is the percentage of error in measuring it. Parallax should be avoided as much as possible. Since a semi-circular piece remains semi-circular even when its temperature varies, there is no error in reading degrees with a protractor due to temperature variation.

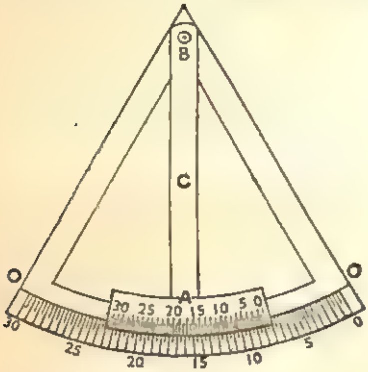


Fig. 32—Angular Vernier

Angular Vernier

Where a greater accuracy in measuring an angle is required, an angular vernier is used in conjunction with a circular scale. The apparatus to show the model of a circular vernier consists of an wooden piece OO bent into the form of an arc with centre B (Fig. 32). It is graduated in degrees or in half degrees. Just along the side of the main scale, another wooden piece A rotates about the common centre. This piece is also graduated in such a way that a certain number $n-1$ divisions of the main scale coincide with n divisions of the vernier scale (generally 29 divisions coinciding with 30 vernier divisions or 59 with 60).

The least count of the vernier is the difference of one scale division and one vernier division. Since $n-1$ scale divisions $= n$ vernier divisions—,

$$1 \ v.\ d. = \frac{n-1}{n} s.\ d.$$

$\therefore$ $1\ s.\ d. - 1\ v.\ d. = 1 - \frac{n-1}{n} = \frac{1}{n}$ part of the value of scale division = vernier constant.

In the particular apparatus (Fig. 32), it is to be noticed that 1 scale division = 0·5° ; also 30 $v.\ d. = 29\ s.\ d.$

$$\therefore \text{ vernier constant} = \frac{1}{30}\text{scale div.} = \frac{0{\cdot}5}{30} = \frac{1^\circ}{60} = 1'.$$

If now, to read a particular angle, the vernier zero is found to lie between 9° and 9·5° and the vernier 13th line to coincide with a main graduation, the main scale reads 9° and the fractional part is obtained by the product of the least count and the number of vernier divisions *i.e.*, $1' \times 13 = 13'$. Therefore, the total reading is 9°13′. Angular vernier capable of reading upto 10″ are fitted with spectroscopes, sextants and accurate direction finders.

Spirit level

The spirit level consists of a sealed glass tube filled almost completely with alcohol except for a small space within it containing an air bubble. The tube is slightly curved with its convex side upwards and is enclosed within a brass casing with a flat base and having an opening at the top (Fig. 33) The casing is so constructed that if it is placed on a truly horizontal surface, the air bubble is below a central line P. A spirit level is used to test whether a surface is horizontal and also to make a plane surface horizontal if there are proper arrangements to level it.

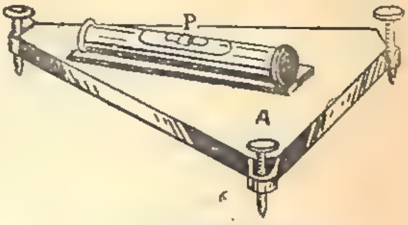


Fig. 33—Spirit level

Suppose that the triangular base A of fig. 33 is to be made horizontal with the help of three base screws. To do this, the spirit level is placed with its axis parallel to the line joining *any two* base screws and the air bubble of the spirit level is brought to the centre by working any one or both the screws. Then the spirit level is placed at right angle to its original position and again the bubble is brought to the centre by turning *only* the third base screw. Thus, the two rectangular straight lines on the plane base being horizontal the plane itself becomes horizontal.

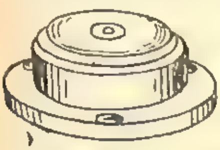


Fig. 34

There is another type of spirit level called circular level (Fig. 34) which consists of a small cylindrical metal box having a convex glass cover at the top. The box is almost completely filled with alcohol except for a bubble of air, which floats above and lies in contact with glass. The box is provided with a plane base and is designed in such a way that when it is placed on a horizontal surface, the bubble is at the centre of the cover. The use of such a level is similar to that of an ordinary spirit level.

Plumb line

A plumb line consists of a conical piece of metal bob B suspended by a thread from a support O (Fig. 35). There is another conical piece C beneath the bob fixed to the support. The base A is provided with levelling screws L The point of support of the string is so selected that when the upright is truly vertical, the apex of the cone B is just above that of C.

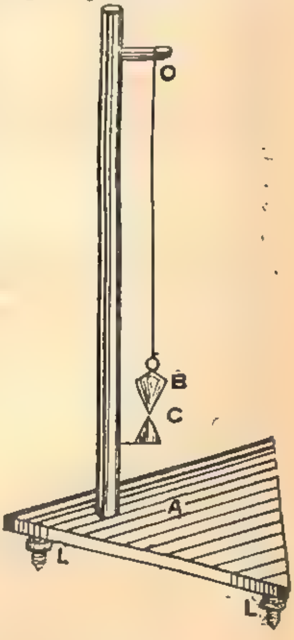


Fig. 35—Plumb

A plumb line is used to examine the verticality of a line or a plane and is always used by masons in the construction of walls.

There is another form of plumb line in which the suspended string carrying the bob passes through a ring fixed to the support. When the upright is made vertical the string passes through the centre of the ring. Balances for the measurement of mass are mostly provided with plumb lines.

Units of Mass—The unit of mass on the C. G. S. system is a kilogramme and is defined to be the mass of a certain lump of platinum preserved at Archives de Paris. It is also practically the mass of a litre of pure water at 4°C. The submuliples of a kilogramme are the following :—

1 kilogramme (kg.) = 1000 grammes (gm.)
1 gramme = 10 deci-grammes (dg.)
1 deci-gramme = 10 centi-grammes (cg.)
1 centi-gramme = 10 milli-grammes (mg.)

The unit of mass on the British system is called the pound avoirdupois and is defined to be the mass of a certain lump of platinum preserved at the Office of Exchequer, London. The multiples and submultiples of a Pound are,

1 Ton = 20 Hundred Weights (cwt.)
1 Hundred weight = 112 Pounds (lb.)
1 Pound = 16 Ounces (cz)
1 Ounce = 16 Drams (dr.)
1 Pound Avoirdupois = 7000 Grains.
1 Pound Troy (Jeweller's or Apothecaries' Weight) = 5760 grains.
The relation between the two systems of units is given below—
1 gramme = 15·432 grains
1 pound = 453 56 grammes.

Fig. 36

Spring Balance—It consists of a spiral of steel enclosed in a metallic case (Fig. 36). The upper end of the spring is rigidly fixed to a ring at the top of the case and its lower end is attached to a straight metal rod (within the casing) carrying a hook at the bottom. The instrument is provided with a plate at the front with a long narrow slit which is graduated on either side in pounds or kilogrammes. A pointer attached to the rod projects out of the slit and rests against the scale and is so designed that when there is no load attached to the hook the pointer reads zero of the scale.

When using a spring balance, it should be suspended by its ring from a rigid support in a vertical position. The mass to be measured is suspended from the hook. The weight of the mass pulls down the hook and its attached rod downwards with a force proportional to the mass and this force stretches the spring which is thereby extended. The pointer is consequently shifted downwards to some other part of the scale indicating the mass suspended in pounds or kilogrammes.

In order to calibrate the scale of the spring balance different *known* standard masses are suspended from the hook and the positions of the hook are marked on the edge of the slit with corresponding numbers. The intervening space between any two marks are divided into a suitable number of equal divisions.

Spring balances provided with different grades of springs are used for various ranges of weights; the one having a thick steel spring is used for big loads and the other having a brass spring can measure a fraction of an ounce. Spring balances of various ranges giving scale readings from 1 lb. to 400 lbs. are available in the market.

Common Balance—It consists of a horizontal metal frame work B (Fig. 37) capable of turning freely with very little friction about an agate knife edge at its centre, called the *fulcrum.* The beam is usually graduated at one or both the arms into 50 or 100 equal divisions. The agate knife edge rests on a small horizontal plate of steel at the top of the vertical pillar within the metal casing V. The ends of the beam carry two *stirrups* or pan-supporters E, E. being supported on two other knife edges. Two identical adjustable nuts or screw-riders C, C, work at the extremities of the beam on screw-cut extensions.

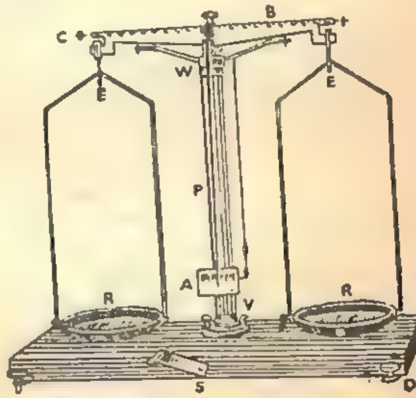


Fig 37 Balance

Two scale pans R, R, are suspended from the stirrups. One end of a long metal pointer P is attached to the middle of the beam and its lower end is in front of a graduated scale A. When the beam swings, the end of the pointer oscillates to-and-fro over the scale A. When the balance is not used, the pillar supporting the beam is lowered by turning a handle S at the base, such that it rests on a rigid frame W. The sharpness of the agate of the beam is thereby preserved. A plumb line is suspended from this frame and is used to make the pillar vertical with the help of base screws. A few balances are provided with spirit levels on their bases instead of plumb lines. The instrument is always kept in a glass

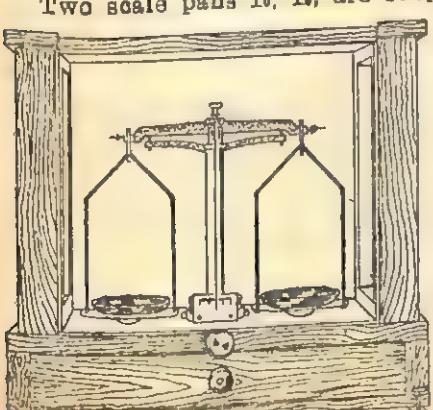


Fig. 38

case to prevent it from being disturbed by wind when weighing is carried out and also from being contaminated with acid fumes and moisture. The balance, preserved as usual in a glass case is shown in Fig. 38. A horizontal rod, just above right arm of the beam, can be slided in or out and is used to adjust a rider weight on the beam whenever necessary.

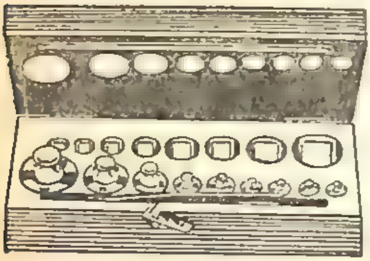


Fig. 39—Weight Box

Standard weights from 100 gm to 10 mg. are supplied in an wooden box called *weight box* (Fig. 39). The heavier weights are made of brass and the lighter ones of aluminium. A pair of tongs or forceps to remove the weights is also supplied at one side of the box.

Principle of Weighing—The beam B of the balance serves as a lever of Class 1, in which the *central* agate knife edge is the fulcrum about which the lever rod can rotate. The two other *terminal* knife edges, carrying the stirrups EE, form the regions of the lever where the 'effort' and the 'resistance' work. In every balance, meant for weighing, the central knife edge is *exactly at the middle region* of the length between the terminal knife edges so that the fulcrum is at the middle point of the lever.

Moreover the beam has a certain mass and so it has a *fixed* centre of gravity; but when adjustable screws CC, the stirrups and the scale pans RR are mounted on the beam, the position of *combined* centre of gravity *changes.* The essential condition to be satisfied by a balance is such that the combined C. G. of the balance beam and its requisites must be a *little vertically below* the central agate, so that when the beam is raised up, it might oscillate a few times before coming to rest in a *horizontal position.* More about it would be discussed in the article on Sensitivity of a Balance (vide Appendix).

Let the length of each *half* of the effective balance beam be l. Let a body of mass m be placed on the left pan and some standard 'weights' of combined mass m' be placed on the right pan, so that when the beam is raised, it still remains horizontal. The weight mg of the mass is resistance and the weight $m'.g$ is the effort. For equilibrium of the system, the turning moments must be equal and opposite. Hence $mg \times l = m'g \times l$ or $m = m'$.

Conditions to be satisfied by a Balance—A good balance must have to satisfy the following conditions. It must be (i) *tru*, (ii) *sensitive* and (iii) *stable.*

In order that a balance may be true, the beam when raised up remains horizontal when the pans are empty or loaded with equal masses. This condition requires that the two arms of beam with respect to the fulcrum must be of equal length and the centre of gravity of the beam must have to pass through the agate knife-edge. Further the scale pans must be of equal masses. Under the condition the moment of the weight of each scale pan with respect to the point of support is equal to one another.

In order that a balance may be **sensitive**, a small difference in the masses of the bodies placed on the pans would appreciably make the beam inclined from

its position of horizontality. This requires that the beam should be light and the arms should be long. Further the centre of gravity of the beam should be *very near the fulcrum.*

In order that a balance may be stable, the beam when disturbed becomes horizontal after a few oscillations. The stability increases more and more as the centre of gravity of the beam with components is pushed below the fulcrum. This condition is opposed to one of the conditions of sensitiveness and a compromise is sought between the two.

Preliminary Observations and Adjustments

The following procedure should be always followed before using a balance,—

(*a*) Open the glass case and examine the plumb line. If it correctly hangs, the pillar is vertical. If not, adjust the levelling screws properly to bring the plumb line into the correct position.

(*b*) Then observe whether the various parts of the balance are in their proper positions, i.e. whether the stirrups are on their knife-edges, scale pans are suspended from the stirrups etc. If not the parts should be properly placed.

(*c*) If found dusty, cleanse the scale pans thoroughly with a soft brush.

(*d*) Gently turn the lever at the base to raise the beam without any jerk when the pointer is found to oscillate slowly over the scale. The extent of oscillations of the pointer should be *nearly* equal on both sides of the central mark.

If unequal oscillations are noticed, it indicates that the turning moments of the two halves of the beam about the central knife-edge are not *exactly* equal. To correct it, lower the beam and screw in the nut slightly on the side of the arm having greater depression. Again raise the beam and observe the oscillations of the pointer and if still found unequal, work the nuts properly. In this way the oscillations of the pointer over the scale should be made equal by repeating this procedure taking care to *lower the beam every time before using the nut rider.* When this is done the balance is ready for use.

Directions while Weighing—The following are the directions that must be observed while weighing a body in an *adjusted* balance,—

(*a*) Put the body on the *left* pan and place any suitable standard 'weight' on the right pan.

(*b*) Any standard 'weight' should be transferred to the pan by forceps only and not by fingers. Weights should not be placed anywhere except the pan or the box.

(*c*) By repeated trials 'weights' should be placed to counterpoise the body always commencing from the highest possible weights and gradually going down to lower 'weights',

(*d*) To check the equilibrium of the balance beam while such preliminary trials are made, the beam should not be fully raised by the key as otherwise there should be unnecessary jerk and knife edges might be injured.

(*e*) When equilibrium is nearly obtained, the beam should be fully raised and the oscillations of the pointer are observed. While making final adjustments with small weights, every time the beam should be lowered before adding or taking away such weights.

Methods of Weighing

Different methods are adopted to secure accurate weighing under different circumstances. These are (i) Method of oscillations (ii) Using a rider (vide Appendix).

Methods of Oscillations—If the balance is correctly adjusted, the pointer oscillates *nearly* equally on either side of the central mark with empty pans when the beam is raised. The body to be weighed is placed on the left pan and suitable weights are placed *by trial* on the right pan, till on making the beam free, the pointer oscillates almost equally on either side. The resting points of the pointer with empty pans and with loaded pans are computed from the extents of oscillations of the pointer and thence the mass of the body is calculated (vide pp. 60-61).

Comparison of a Spring Balance with an Ordinary Balance

It should be borne in mind that common balance compares the mass of a body with the mass of standard weights, while a spring balance records the amount of pull of the gravity on any mass. As the acceleration due to gravity changes from place to place on the surface of the earth, a spring balance, if made very sensitive, may exhibit the variation in the weight of a body. The calibration of the scale of a spring balance at a particular place may not tally with that made at some other place. But in a common balance the weight of the mass and that of the weights are equally affected by a change of locality and the position of equilibrium does not change. Hence with a common balance the standardisation of the weights remains invariable.

Date— EXPERIMENT 9

To Weigh a Body in a Physical Balance

Theory—If the oscillations of the pointer of a balance be nearly equal on either side of the central mark with empty pans and if the oscillations be nearly equal when a body is placed on one pan and a total load w on the other, then the mass of the body is equal to the mass of the total loads placed.

Apparatus—A physical balance, a small piece of marble and a weight box.

[A brief description of a balance and a weight box is necessary here; vide pp. 55 & 56.]

Procedure—Before attempting to weigh a body with the balance supplied, see that the plumb line points exactly against the lower pointer. If not, adjust the levelling screws at the base of the balance to bring the plumb line upon the pointer. When this

is done, the pillar of the balance has been made vertical. Turn the key at the base, the raise the beam and observe oscillations of the pointer. If oscillations are unequal, set the position of the adjustable nuts over the scale. [See preliminary directions on p. 56]. The balance is now ready for use.

Then place the body to be weighed, say a piece of marble on the left pan and take out from the weight-box with the help of forceps a brass weight, likely to counterpoise the body, and place it on the right pan. Raise the beam *slightly* and observe the deflection of the pointer. If the beam of the balance is found to be permanently depressed on the side of the body, then the body is much heavier than the weights placed. In this case add additional weights in their descending order on the right pan, care being taken to lower the beam each time a weight is added. But if the case is reverse, try with a lesser weight by removing the former weight

Finally place a set of weights on the right pan by trial such that the pointer oscillates equally on both the sides. Then, the total load on the right pan is equal to the mass of the body Take three such sets of readings and calculate their mean value which represents the mean mass of the body.

Results—

Loads on: Left Pan	Loads on: Right Pan	Total Load on the R. Pan	Deflection of the pointer	Inference about the magnitude of weights
	gm.	gm.		
A piece of marble	20	20	to the right	too small
	20+10	30	to the left	too great
	20+5	25	to the right	too small
	20+5+2	27	to the right	too small
	20+5+2+1	28	to the left	too great
	20+5+2+0·5	27·5	to the right	too small
	27+0·5+0·2	27·7	to the left	too great
	27+0·5+0·1	27·6	to the left	too great
	27+0·5+0·05	27·55	to the right	too small
	27·5+0·05+0·02	27·57	to the left	too great
	27·5+0·05+0·01	27·56	equal oscillations	equal to that of the body

Hence the mass of the body = 27·56 gm.

Discussions—The various parts of the balance should be checked and examined before use. If any part is found displaced, it should be placed properly and the balance should be made as free as possible. The rider nuts should be so adjusted that with empty pans the pointer oscillates equally on both the sides of the zero on the scale. The weights should also be held with forceps and should not be placed anywhere except within the weight box or on the pan

If the balance is found to be appreciably sensitive with 0·01 gm., the probable error in measuring a mass of 27·56 gm. might be ±0·01 gm. Therefore, the percentage of error is 0·04%.

Determination of Resting point of an Oscillating pointer.— If the balance is *very sensitive*, it may not be possible exactly to counterpoise the body with suitable weights in the weight-box. With some weights, say m gm., on the right pan and the body on the left, it may be found that the body is just heavier. Then, on adding the smallest possible weight available in the weight-box, say 10 mg., it may be found that the body is just lighter. It is evident then that the mass of the body is between m gm. and m gm. + 10 mg. Determination of the mass of the body, under this circumstance, can be made from calculation of the shift of the resting points of the pointer or by using a rider. We shall now consider the method of oscillations.

At first adjust the screw nuts of the balance so that with empty pans the pointer oscillates almost equally on both sides of the central mark. Observe the successive turning points of the pointer over the scale; it would be found that that the extent of swing of the pointer gradually dies away.*

Suppose that the scale is graduated from 0 to 40 in equal divisions such that 20th graduation corresponds to its middle point. (Fig. 40) In course of oscillations, note the turning point of the pointer on the scale, when it comes *once to the left*. Then follow the end of the pointer till it goes to the extreme right and just as it stops to turn back, read the scale. Read again the scale when the pointer comes to extreme left. In this way record altogether 3 or 5 consecutive turning points, either two *the left and one to the right* or *three to the left and two to the right.* Then find the mean of the left end readings and that of the right end readings. Finally, calculate the mean of these two mean readings which represents the resting point. Let it be P.

For example, suppose that when the pans are empty and the balance is free, the successive swings of the pointer are shown as in fig. 40 (top). The successive readings are 7, 31·5, 9·5, 29, 12. Of these the left end readings are 7, 9·5 and 12; their mean value is 9·5. The right end readings are 31·5 and 29 having a mean value of 30·25. Therefore, the resting point for empty pans is the mean of 9·5 and 30·25 which is 19·9. Find two to three sets of readings for empty pans and calculate the resting point from each set of readings. The mean of these readings represents the true resting point.

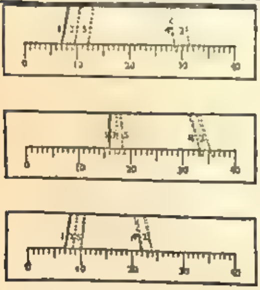


Fig. 40

* This happens because there is always some friction at different parts of the balance as it swings; secondly, because air exerts some resistance to the motion of the parts of the balance particularly of the balance pans. Due to the diminution of successive swings the pointer would ultimately come to a dead stop at some part of the scale, which is called the resting point of the pointer. But as this is a question of time, the worker has got to wait till the pointer comes to rest. There is, however, a method of determining the resting point of an oscillating pointer by observing its successive turning points.

Then place the body and the weights as usual on the pans so as to be nearly counterpoised. It is desirable to place weights of *slightly* smaller mass than that of the body, such that the pointer oscillates to a greater extent on the right half of the scale. Take a similar set of readings for the turning points and find the mean. Let it be Q.

Next, add the lowest available weight of the weight-box (generally 10 mg.) to the weights already placed on the pan and take a similar set of readings for the new resting point, which will now shift to the left of Q. Let it be R. Finally, make the calculation of the fractional mass in the following way:

The pointer shifts through (Q—R) divisions for adding of ·01 gm.

$\therefore$ the pointer shifts unit division for addding of $\frac{\cdot 01}{Q-R}$ gm.

$\therefore$ it shifts (Q—P) for addition of $.01\ \frac{Q-P}{Q-R}$ gm.

Thus the mass of the body is $\left(m + \cdot 01\frac{Q-P}{Q-R}\right)$

Reduction of Weighings to Vacuo

Since we ordinarily weigh everything in air, it loses a part of its weight, by Archimedes' principle, equal to the weight of displaced air. The true weight of a body is its weight in vacuum. When we weigh a body in air, the apparent weight of the body is equal to the apparent weight of the 'weights' placed on the balance pan. Let the apparent weight of the body = M gm., true weight $= M_0$ gm., the density of the body $= \delta$ and density of air at the observed temperature and pressure $= \sigma$. Then, by Archimedes principle the mass of displaced air is $\frac{M\sigma}{\delta}$. Therefore, $M_0 - \frac{M\sigma}{\delta}$ = apparent mass of the body = apparent mass of the weight $= M - \frac{M\sigma}{D}$ where D = density of the material of the weights.

$$\therefore \quad M_0 = M + M\sigma\left(\frac{1}{\delta} - \frac{1}{D}\right)$$

Date—

EXPERIMENT 10

To weigh a Body by the Method of Oscillations and to apply Buoyancy Correction

Theory—If, with empty pans, the resting point of the pointer of the balance be P, and with a body on one pan and a load m gm., on the other pan, the resting point be Q and with the body on the same pan and a load $(m+w)$ gm., on the other, the resting point be R, then the apparent mass of the body in air is equal to

$$\left(m + w\frac{Q-P}{Q-R}\right) \text{ gm.} = M \text{ gm. say,}$$

Then if M_o represents the mass of the body in vacuo, then

$M_o = M + M\sigma.\left(\frac{1}{\delta} - \frac{1}{D}\right)$ where δ = density of the body, D = density of the weights and σ = density of the air at the observed temperature and pressure.

Apparatus – A physical balance, a weight-box and a small piece of glass.

[A description of a balance is to be given here, *vide* p. 55]

Procedure – For procedure *vide* p. 58.

Results—

No. of readings	Load on Pans		Readings of the pointer		Mean Readings		Mean	Resting Point
	Left	Right	Left	Right	Left	Right		
1	0	0	7·0 9·5 12·0	31·5 29·0	9·5	30·25	19·9	19·7 = P
2	0	0	11·0 12·5 14·0	27·5 25·5	12·5	26·5	19·5	
3	A piece of glass	11·57 gm.	16·0 17·5 18·5	35·0 33·5	17·33	34·25	25·8	25·85 = Q
4			19·0 20·0 20·5	32·5 31·5	19·8	32·0	25·9	
5	Same piece of glass	11·57 gm. + 0·01 gm. = 11·58 gm.	7·0 8·0 10	24·0 22·0	8·5	23·0	15·8	15·85 = R
6			10·5 11·5 12·5	21·0 19·5	11·5	20·25	15·9	

(b) Calculations for Mass of the Glass piece.

The shift is (25·85 – 15·85) = 10 divisions for addition of ·01 gm.

∴ ... ... 1 division ... ... ·001 gm.

∴ ... ... (25·85 – 19·7) = 0·15 ... ·0061 gm.

Therefore, the mass of the piece of glass = (11·57 + 0·0061) gm.
= 11·5761 gm.

Vacuum Correction—Density of glass = 2·52 gm./c.c. = δ.

Density of brass weights = 8·3 gm./c.c. = D. Density of air at the observed temperature 26°C and pressure 75·8 cm. of mercury = 0·00128 gm./c.c. = σ.

Then substituting in the equation,

$$M_o = 11{\cdot}5761 + 11{\cdot}5761 \times {\cdot}00128\left(\frac{1}{2{\cdot}52} - \frac{1}{8{\cdot}32}\right)$$
$$= 11{\cdot}5797 \text{ gm.}$$

Discuss'ons—The eye-estimation in reading the turning points of the pointer over the scale may be taken correct to half a division. This ensures a measurement of the shift correct to the first decimal place. Further a shift correct to one place of decimal measures a difference of mass upto the 4th place of decimals, the mass of a body can be taken correct to the 4th place of decimals by the method of oscillations.

The accuracy with which the mass of a body can be measured depends to a great extent upon the sensitivity of the balance. A shift of 10 divisions for addition of ·01 gm. speaks of a good sensitiveness.

Determination of resting point might possibly have an error of $= \frac{1}{2}$ a division. This is equivalent to an error of $=$ ·0005 gm. Hence percentage of error is

$$= \frac{\cdot 0005 \times 100}{11 \cdot 5761} = \cdot 005\%$$

ORAL QUESTIONS

Define resting poi t of a pointer. What are advantages of taking resting point? Why is it that the successive oscillations of the pointer gradually decrease? What is the accuracy with which a mass can be measured when the lowest available weight in the weight-box is 5 mg. and the shift for this weight is 6 divisions. What is vacuum correction? Does a body weigh more in air or in vacuum? Why? Why should the arms of a balance be of equal length? Explain why sensitive balances have slower oscillations.

Units of Area—This unit is derived from the unit of length, The unit of area on the F. P. S. system is a *square foot* and that on the C. G. S. system is a *square centimetre.*

Measurement of Area

Geometrical Method—Areas of regular geometrical figures can be calculated from the following formulae.

Area of a square $=$ (each side)^2
" " Rectangle $=$ length $\times$ breadth
" " Parallelogram $=$ base $\times$ altitude
" " Triangle $= \frac{1}{2} \times$ base $\times$ altitude
" " Trapizium $=$ sum of parallel sides $\times$ altitude
" " Circle $= \pi \times$ (radius)^2
" " an Ellipse $= \pi \times$ semi-major axis $\times$ semi-minor axis
Surface of a Sphere $= 4\pi \times$ (radius)^2
" " Cylinder $= 2\pi \times$ radius $\times$ length

Other closed figures bounded by straight lines on all sides can be suitably subdivided into a number of triangles. The total area of the triangles, thus formed, gives the area of the figure under investigation.

For example, the area of a rectangular surface, whose base is found to be 70·52 cm. and altitude 50·31 cm. is $70 \cdot 52 \times 50 \cdot 31 = 3547 \cdot 85$ sq. cm. The area of a circular surface of radius 13·62 cm. is $\pi \times 13 \cdot 62^2 = 3 \cdot 14 \times 13 \cdot 62^2 = 582 \cdot 47$ sq. cm. The area of a sphere of the same radius is $4\pi \times (13 \cdot 62)^2 = 2329 \cdot 88$ sq. cm.

Weighing Method—The area of a *plane* figure of any shape may be found by the following method. The figure is placed on a thin metal sheet of *uniform* thickness and its outline is drawn with a fine pencil. It is then cut out and weighed in a balance. Let it mass be W gms. From the same sheet, a rectangular piece is taken out and its surface area is measured. Let it be s sq. cm. It is then weighed in a balance. Let it be w gms. Then if the required area be S sq. cm. then,

$$\frac{S}{s}=\frac{W}{w} \text{ or, } S=\frac{W}{w}s \text{ sq. cm.}$$

Alternatively, if the density of the metal sheet is ρ gm/c.c. and thickness of the sheet is x cm., the area of the figure is S sq. cm. and the mass of the figure W gm.

Then, $Sx\rho=W$ or, $S=\frac{W}{x\rho}$ sq. cm.

These methods are not very accurate, because the cutting out of the figure from the lamina entails some error regarding the exactness of shape ; moreover the metal sheet might lack in the uniformity of thickness.

Date— EXPERIMENT 11

To find the Area of an Ellipse by Weighing Method

Theory—If W be the mass of an area S drawn upon a uniform laminar sheet and if w be the mass of a known area s drawn upon the same sheet, then

$$S=\frac{W}{w}s \text{ in whatever units they are expressed.}$$

Apparatus—An elliptical metallic sheet, a rectangular sheet of the same metal and of same thickness, a vernier callipers, a balance and a weight-box.

Method—Weigh the elliptical metal piece in a balance accurate upto a centigram. Take three such weights and find the mean value. Then weigh the rectangular metal piece and find its mass also in a similar way, by taking three separate readings.

Now, take the rectangular piece and measure its length with a vernier callipers at three different regions. The mean value gives the length. In a similar way measure its breadth. Then from the formula, calculate the area of the ellipse.

Results—

No. of readings	Mass of ellipse = W gm.	Mean mass gm.	Mass of rectangle = w gm.	Mean mass gm.	Ratio W/w
1 2 4	115·66 115·66 115·66	115·66	11·23 11·24 11·24	11·24	10·29

Callipers : main scale graduated in millimetres

10 vernier divisions = 9 main scale divisions

∴ Least count = 0·1 mm. = 0·01 cm.

No. of readings	Length of Rectangle = l		Breadth of Rectangle = b		Area sq. cm. $l \times b$
	Total M+Vs cm.	Mean cm.	Total Ms+Vs cm.	Mean cm.	
1 2 3	3·51 3·51 3·50	3·51	2·00 2·01 2·01	2·01	7·055

Hence area of ellipse = 10·29 × 7·055 = 72·59 sq. cm.

Verification by Geometrical Method

Take a vernier callipers and find its least count as well as the instrumental error, if any. Open the jaws of the callipers widely and place the elliptical figure with its major axis *in contact* with the jaws. Take the reading of the callipers. Take three such readings. Now place the minor axis of the ellipse in contact with the jaws and in a similar way take three such readings in a *tabulated* form. Finally considering the zero error, get the mean values of the major and minor axes.

The mean value of the major axis considering zero error = 12·14 cm. The mean value of the minor axis considering zero error = 7·62 cm. Hence, applying the geometrical method, the area of the given ellipse is found to be $\pi \times \frac{12·14}{2} \times \frac{7·62}{2}$ sq. cm. = 72·61 sq. cm.

Discussion—It is very difficult to make a very clear-cut geometrical figure out of a metal sheet unless it is specially made. There might be some error in measuring the major and minor diameters of an ellipse. The difference in area determinations by the two methods has actually been 0.02 sq. cm. in an area of 72·6 sq. cm. Hence percentage of error is 0.03%.

Graphical Method—The figure is drawn on a graph paper on a suitable scale. The total number of small squares included within its boundary is counted. The number of squares *cut by the boundary line* is counted by an approximation on the basis that if less then half the area of a square is within the boundary, it may be omitted whereas if more then half the area lies within the boundary, it is taken as one. If n be the total number of squares within the area and if s be the area of a small square on the same scale as that of the figure, then the total area S of the figure is given by $S = n \times s$. This method of area measurement is also not very accurate particularly if the boundary line enclosing the area be irregular.

Date— EXPERIMENT 12

To Determine the Area of a Circle by Graphical Method

Theory—If any closed curve is drawn on a graph paper on a suitable scale, then the area enclosed by the curve is equal to the product of the area of a small square of the graph paper and total number of elementary squares included within the figure.

Apparatus—A graph paper, drawing board, a few fixing pins, drawing pencil and a compass.

Method—Fix a piece of graph paper on a drawing board by pins. Choose a suitable origin O at the central part of the graph paper and draw two co-ordinate axes. With O as centre and with any radius draw a circle XYX_1Y_1 with a compass (Fig. 41). Measure the radius of the circle with a divider and metre scale. Thus, four quadrants of the circle are obtained, *viz*, YOX, YOX_1, X_1OY_1 and Y_1OX. Count the number of small squares in each quadrant *separately*. If the curve happens to pass through a small square such that the greater half is within the circle, count it as one whole. If, on the other hand, the major part of a square lies outside, reject it. Finally add the numbers of the squares in all the four quadrants to get the total number of squares. Find the area of a small square and multiply it by the total number of squares.

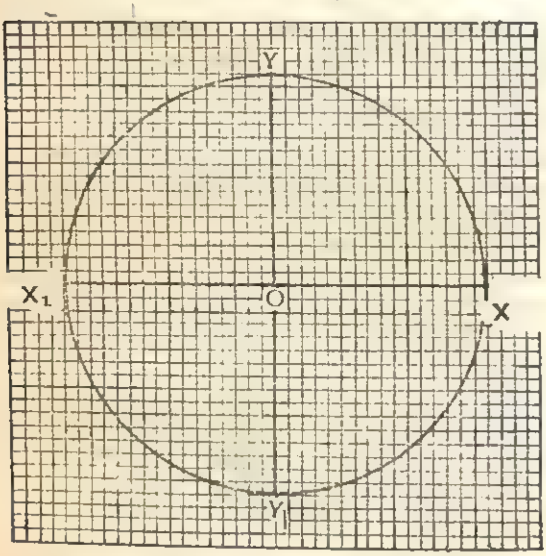


Fig. 41—Graphical Measurement of Area.

Results—

Measurement of Radius of the Circle.

No. of readings	Left side readings cm.	Right side readings cm.	Difference cm.	Mean r cm.	Area πr^2 sq. cm.
1	2·0	3·6	1·6	1·60	8·04
2	11·1	12·71	1·61		
3	22·4	24·0	1·6		

Counting of Squares.

No. of readings	Quadrant	No. of complete small squares	No. of fractional squares	No. of squares in a quadrant	Total No. of squares	Area of each square sq. cm.	Area of circle sq. cm.
1	XOY	190	11	201			
2	XOX_1	190	11	201	805	0·01	8·05
3	Y_1OX_1	191	11	202			
4	Y_1OX	190	11	201			

Discussions—The calculated value of the area is 8·04 sq. cm. while the graphical value is 8·05 sq. cm. The error is 8·05—8·04 = ·01 sq. cm. in a mean value of 8·05 sq. cm. The percentage of error is therefore ·025%. The principal source of error is the method of approximation adopted in counting the number of squares. The larger is the radius of the circle on the graph paper, the more accurate is the method of integral count. Another source of error is due to the ordinary graph paper on which lines are not accurately equidistant and hence all squares on it are not equal in area.

A student might be tempted to find the total number of squares contained in a circle by counting the number in one quadrant only and then multiplying it by 4. But then there is a chance of committing larger error in this process. Suppose that the percentage of error in counting squares in one quadrant is m%, then multiplying the number by 4 entails a percentage of error of 4m%. Thus, a separate count of each quadrant is advisable.

Evaluation of π—This experiment affords a means of calculating the value of π which represents the ratio of circumference and diameter of a circle. It can be evaluated in the following way. It is known that,

Area of a circle $= \pi \times$ square of its radius.

$$\text{Thus, } \pi = \frac{\text{Area of the circle}}{(\text{radius})^2} = \frac{8·05 \text{ sq. cm.}}{2·56 \text{ sq. cm.}} = 3·14$$

The correct value of π upto 2 places of decimals is 3·14. The sources of error in evaluating this constant are also the same as in the foregoing experiment.

EXERCISES

1. Draw two triangles on the same base and having an equal altitude on a graph paper and hence show that their areas are equal.

2. Draw a map of India on the graph paper on a suitable scale and find its area in square kilometres.

3. Given a circular lamina and a rectangular piece cut out of the same sheet of metal, find the area of the lamina.

Units of Volume

The volume of a substance is a measure of the space occupied by it. The unit of volume is derived from the unit of length

and is the volume of a cube, each side of which is of unit length. This unit on the Metric system is one cubic centimetre (1 c.c), which is the volume of a cube of each side having a length of 1 cm. The unit on the British system is a cubic foot (1 cu ft.). The relation between the two units is as follows :

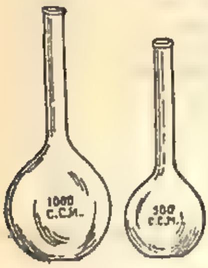


Fig. 42 Flasks

$$1 \text{ foot} = 30{\cdot}48 \text{ cm},$$
$$\therefore\ 1 \text{ cu. ft.} = (30{\cdot}48)^3 \text{ c.c.} = 28315{\cdot}9 \text{ c.c},$$
$$\text{Again, } 1 \text{ cu. ft.} = 12^3 \text{ cu. in.} = 1728 \text{ cu in.}$$
$$\therefore\ 1 \text{ cu. in.} = 16{\cdot}38 \text{ c.c.}$$

The volume of a liquid on the C. G. S. system is generally measured in terms of a litre, which is usually taken to be equal to 1000 cubic centimetres. Glass flasks of standard volumes have got their capacity indicated on their bodies. Two such flasks are shown in Fig. 42 having capacities of one litre and half a litre respectively. Since the volume of a vessel depends on its temperature, the volume as indicated on a flask is standardised at a particular temperature which is also marked on it.

In order to measure the fraction of a litre, special glass jars are constructed having graduations in cubic centimetres. Fig. 43 (*a*) and (*b*) represent two jars, each of capacity 250 c.c. One of them is provided with a stopper and is used to contain volatile liquids or such liquids as would react with atmospheric air. The graduations of the scale begin both ways. The volume of the liquid poured into the jar should be read with the scale beginning from the bottom, whereas the volume of the liquid taken out from the jar is to be referred to the scale beginning from the top.

(a) (b)
Fig. 43

(a) (b)
Fig. 44

Fig. 44 (*a*) represents an ordinary flask for keeping a liquid. In addition to these, there are glass apparatus called burettes, graduated in 0·1 c.c. for measurement of still smaller volumes [Fig. 44 (*b*)].

The British unit of volume for liquids is a gallon, which is equal to the volume of 10 pounds avoir of distilled water at 32°F. The relation between a gallon and a litre is given by the following equivalence :—

$$1 \text{ gallon} = 4{\cdot}54 \text{ litres.}$$

Measurement of Volume

Geometrical method—The volume of regular geometrical shapes may be calculated from their dimension as given below :

The volume of a cube $= (\text{each side})^3$

" " " parallelopiped = length × breadth × thickness

" " " sphere $= \frac{4}{3} \times \pi \times (\text{radius})^3$

The volume of a cylinder $= \pi \times (\text{radius})^2 \times \text{length}$

" " " right circular cone $= \frac{1}{3} \times \pi \times \text{height} \times (\text{radius of base})^2$

Displacement of Liquid—The volume of solid body of any shape, may be experimentally determined either directly or indirectly.

Some liquid, *in which the material of the body is insoluble*, is taken in a graduated jar as that of Fig. 45 and its volume is noted. Next the body whose volume is to be determined is tied with a piece of thin string and is gradually lowered into the liquid until it is completely sunk. The surface of the liquid is found to rise to some higher level which is again read. The difference of the two readings, which gives the volume of displaced liquid is equal to the volume of the solid. If the body is lighter than the liquid, it is tied with another heavy body such that the combination sinks within the liquid. The rise of the liquid level within the graduated jar gives the combined volume of the body and the sinker. The volume of the sinker alone is then measured by the same process. The difference of the two readings is the volume of the body.

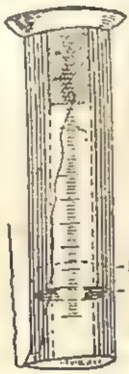


Fig. 45

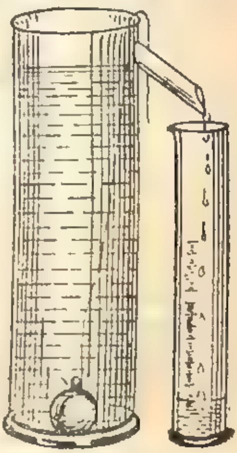


Fig. 46

There is another apparatus working on the same principle. It consists of a tall jar having a spout projecting downwards. (Fig 46) Some liquid is poured into the jar until the liquid is just on the point of overflowing the spout. Then a graduated jar is placed under the spout so as to collect any liquid coming into it. Next the body is tied with a piece of string and is slowly lowered into the liquid so as not to disturb its surface. The overflowing liquid is received in the graduated jar and is measured. The volume of the liquid in the jar is equal to the volume of the solid. The volume of a solid may be found from the Archimedes' principle as is explained in Chapter III of this Volume.

Date— EXPERIMENT 13

To measure the Volume of a Body by the displacement of Water

Theory—When a solid body is completely immersed in an insoluble liquid, it displaces its own volume of liquid.

Apparatus—A liquid displacement jar, a graduated jar, a metallic ball with a hook, some thread.

Procedure—Pour water within the displacement jar until the liquid overflows a little through the spout. When trickling of water through the spout stops, place a graduated jar beneath the spout. Tie the ball with a fine string by the hook and lower it very slowly into the displacement jar until it is completely immersed taking care not to splash water nor to produce waves in it. Then read the volume of water running into the graduated jar with reference to the scale and the fractional part by eye-estimation. The total volume is evidently the volume displaced by the ball. Again, fill the displacement jar with water and collect water by immersing the ball. In this way take three to five readings.

To verify the results, measure the diameter of the ball with a vernier callipers and find its volume from the formula $V = \frac{4}{3} \times \pi$ (radius)^3.

Results—By Displacement Jar.

No. of readings	Initial readings			Final readings			Difference	Mean
	Scale reading	Eye-estimation	Total	Scale reading	Eye-estimation	Total		
	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
1	0	0	0	5	0	5	5·0	
2	5	0	5	10·1	0	10·1	5·1	
3	10·1	0	10·1	15	·05	15·05	4·95	5·03
4	15	·05	15·05	20·1	0	20·1	5·05	
5	20·1	0	20·1	25·1	·05	25·15	5·05	

Diameter of the Ball with callipers supplied.

One main scale division = 1·0 mm.

10 divisions of vernier = 9 divisions of main scale.

∴ Least count of the callipers = 0·01 cm.

Mean diameter = 2·12 cm. ∴ Mean radius = 1·059 cm.

Hence volume = $\frac{4}{3}\pi r^3$ = 4·99 c.c.

Discussions—The jar in which collected water is measured is graduated in 0·1 c.c. with which the volume can be measured accurate upto a tenth of a cubic centimetre. The principal source of error in this experiment is the slight splashing of water when the ball is being immersed. The volume as indirectly measured by callipers is found to be 4·99 c.c. Taking this value as the standard, the percentage of error is nearly 1·0%.

If the solid body is soluble in water, it is to be immersed in a liquid in which it is insoluble and the experiment is carried out as usual. If the solid body is lighter than water, it is tied with another heavy body so that the combination sinks in water. The volume of the combination is first determined by the above method. Then the volume of the heavy body alone is determined in a similar way. The difference of the two volumes gives the volume of the lighter body.

Unit of Time—During the day time when the sun attains apparently the highest position in the sky, it is said to be in the meridian. The interval of time between the passages of the sun across the meridian on any two successive days is called the *apparent*

solar day. It is found that the duration of the apparent solar day varies from day to day throughout a year. If the periods of all solar days in one year be added together and the sum be divided by the number of days, we obtain an interval of time called the **mean solar day.** The unit of time on both the systems is one second which is 86,400th part of a mean solar day. The multiples of a second are the following;

1 mean solar day = 24 hours (hr.)
1 hour = 60 minutes (min)
1 minute = 60 seconds (sec.)

Measurement of Time

It is found that a pendulum* of a given length when oscillating freely through a small arc has got always a definite period of swing. This constancy of period has been utilised in pendulum clocks in regulating time. There is a steel spring within each clock which may be wound with a key. The spring then gradually uncoils and slowly revolves a toothed wheel. The motion of this wheel is controlled by the oscillating pendulum through a number of levers and wheels. The hands of the clock which are connected with the axle of the main wheel consequently revolve continuously with time. The dial of the clock is divided into 60 equal circular divisions, each marking one minute. Thus, a full rotation of one hand measures an interval of one hour. Another hand is so designed that it moves through only 5 divisions during this interval and so one complete rotation of this hand measures 12 hours or half a mean solar day.

Fig. 47—Stop Clock

There is another way of measuring equal intervals of time, and this is done by means of an oscillating wheel called a balance wheel generally found in watches or stop-clocks. One end of a very thin spiral spring is connected to the axle of balance wheel and its other end is fixed with the framework of the watch (Fig. 47). On slightly disturbing the wheel it continues oscillating to-and-fro with a *definite* period. The periodicity of this wheel controls the revolution of the main wheel connected with hands of the watch. Fig. 47 represents a watch capable of measuring seconds. The full dial is calibrated in seconds and the smaller one minutes. There is a

*A pendulum clock consists of a heavy metal bob suspended from a support by a thin solid rod. The bob can be fixed anywhere on the rod. When oscillating, the friction at the support is very small.

key K which when pressed stops the motion of the balance wheel and the watch is instantly stopped. Hence it is called a stop-watch.

There is another type of stop-watch having its dial graduated in a fifth or a tenth of a second (Fig. 48). The nut at the top serves both as the key to wind the watch as well as to start or stop it. When it is pressed downwards the hand starts from 0 to 60 clockwise. At a second press the hand stops and at a third press it jumps back to 0 again, and is ready for another start.

To measure an interval of time with a stop watch the key is pressed just at the beginning of the interval when the second hand starts over the dial from zero. The key is again pressed at the end of the interval to stop the watch. The reading of the hand marks the interval For every complete revolution of the second hand, the minute hand moves through one division. Therefore, minutes should be counted with reference to the smaller hand.

Fig. 48—Stop-watch

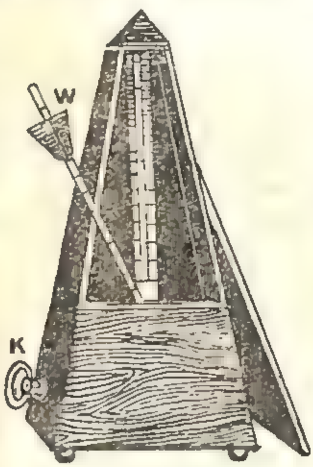


Fig. 49—Metronome

A metronome consists of a metal pendulum capable of oscillating freely about its axis of suspension (Fig. 49). At each end of its swing, a ticking sound is produced. Since oscillations of a pendulum are isochronous, the ticking sounds are produced at regular intervals. Hence a metronome may be used as a time marker. A small weight W can be slided over the pendulum rod and fixed anywhere to change the period of oscillation, and thus the interval between successive ticks can be altered whenever necessary. There is a bell which can be coupled with the pendulum ringing every second, third or fourth interval. This is sometimes used by musicians to keep the timing and rythm of the music.

Oral Questions

What is a mean solar day? Distinguish between a mean solar day and a sidereal day. What is the unit of time in experimental measurements? What is the difference between an ordinary watch and a stop-watch? What is the main principle upon which the working of a clock depends? How does it differ from the working principle of a watch? What is the minimum interval which can be measured by a stop-watch you are using in your laboratory?

CHAPTER II

EXPERIMENTS ON GENERAL PROPERTIES

Force

The term force is defined by Newton's laws of motion. The first law expresses the fact that a force changes or tends to change the state of rest or motion of a material body. The second law states that the force is proportional to the product of the mass and the acceleration produced on the body. The third law states that the action of a force on a body is under all circumstances equal to its reaction by that body. The kind of force may be any one of the nature of pressure, tension, friction, attraction or repulsion etc.

The absolute *unit of force*, derived from the second law, *is that force, which acting on a unit mass, produces a unit acceleration.* In the F. P. S. system this unit is called a **poundal** and is equal to the force, which acting on a mass of one pound produces an acceleration of one foot per second per second. In the C. G. S. system the corresponding unit is a **dyne** and is equal to the force producing an acceleration of 1 cm. per sec. per sec. on a mass of 1 gm. [For a detailed explanation of Newton's laws, *vide* Basu and Chattejee's Intermediate Physics, Part I, Chap. III.] There is a third and most recent system, known as Metre-Kilogram-Second system (MKS) in which a unit force is defined to be that force which acting on a mass of one kilogram produces on it an acceleration of one metre per second per second. This unit of force is called a newton. The force is a vector quantity.

The Gravitational unit of force is equal to the weight of a unit mass. In the F. P. S. system this unit is the weight of a pound and in the C. G. S. system it is the weight of a gramme.

From Newton's second law we know that force = mass × acceleration. Since the weight of a mass is equal to the force with which the earth attracts it, the mass on being released from a height falls down with an acceleration of g cm. or ft. per sec. per sec. Hence if w = weight of a mass m, then, $w = m \times g$, where g = acceleration due to gravity. The standard value of g in the F. P. S. unit is 32·2 ft per sec.^{2} and in the C. G. S. unit it is 981 cm. per sec.^{2}. Thus

$$1 \text{ lb weight} = 32{\cdot}2 \text{ poundals}$$
$$1 \text{ gm. weight} = 981 \text{ dynes}$$

Again, $1 \text{ poundal} = \dfrac{1}{32{\cdot}2} \text{lb. weight} = 0{\cdot}031 \text{ lb wt.}$

$$1 \text{ dyne} = \frac{1}{981} \text{gm. wt.} = 0{\cdot}00102 \text{ gm. wt.} = 1 \text{ milligram nearly}$$

$$1 \text{ newton} = 1 \text{ kg} \times 1 \text{ metre/sec}^2 = 10^5 \text{ dynes}$$

Composition of Forces—If a particle is simultaneously acted on by two forces along the same straight line the *resultant* force

is equal to the algebraic sum of the forces if they act in the same direction and it is equal to the difference of the forces if they act in opposite directions. If the two forces act in directions inclined to each other, the resultant is given by the Parallelogram Law, which states the following :—

If two forces acting simultaneously at a point be represented in magnitudes and directions by the adjacent sides of a parallelogram drawn from the point, their resultant is represented in magnitude and direction by the diagonal of the parallelogram passing through that point (Fig. 50).

To consider the equilibrium of a particle acted upon by three forces, there is another law called the Triangle of Forces, which states that, if three forces acting on a particle be represented in magnitudes and diretions by the sides of a triangle taken in order, the forces are in equilibrium (Fig. 51). Since the quantity force has some specific direction and magnitude, it is called a *vector*. The vector obeys the laws of addition, subtraction, multiplication and division in some modified manner. [*Vide* Basu and Chatterjee's Intermediate Physics, Part I, Chap. III.]

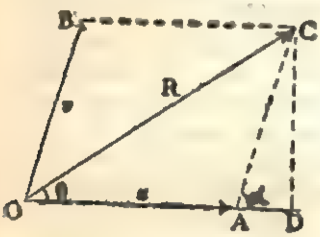


Fig. 50

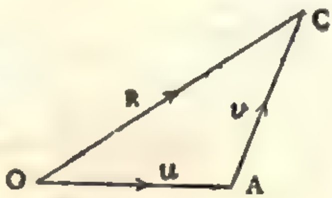


Fig. 51

Date—

EXPERIMENT 14

To Verify the Law of Parallelogram of Forces

Theory—If two forces P and Q acting simultaneously at a point be represented in magnitudes and directions by the adjacent sides of a parallelogram drawn from the point, their resultant R is represented in magnitude and direction by the diagonal of the parallelogram passing through that point.

Apparatus—A black board, two frictionless pulleys, a small ring, three weight hangers and a few standard weights. [A diagram of Fig. 52 is to be drawn on the blank page of the Fair Note Book].

Procedure—Fix up two very light pulleys PP at the two corners of a black board fixed vertically (Fig. 52). Suspend two identical scale pans from the ends of two stout silk threads and pass the threads over the pulleys. Fix up the other ends of the threads to a small ring at O by loose knots. Suspend another scale pan of equal mass from the ring. Set up three small stools about one foot below the scale pans, as a measure of safety, so that the scale pans may not crash down on the floor.

Place a known weight on the middle scale pan and place suitable weights on the side scale pans to obtain a balance so that the pans with their loads all hang in air. The load on each pan together with the mass of the pan records the tension on the corresponding string. Find the mass of each load on the pan. Take out the loads and find the mass of the pans. Let W_1, W_2 and W_3 be the total loads including the respective masses of pans.

On the black board draw a line OB parallel to one thread of length proportional to W_1 and another line OA parallel to other thread of length proportional to W_2. Complete the parallelogram OARB and draw the diagonal OR. Take a plumb line and suspend it from a vertical stand and bring the point of suspension at R. It would be found that OR is vertical and is along the string carrying W_3. Measure the length OR, which would be found proportional to W_3. Hence, the resultant of W_1 and W_2 is W_3. Take three sets of readings each time altering the lengths of the strings and the loads on the carriers. Measure the angle BOA with a protractor. Let it be θ say. Then according to the parallelogram law,

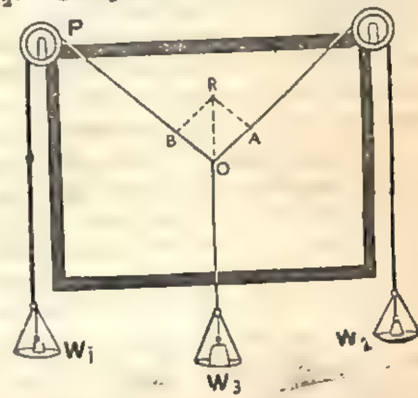


Fig. 52—To verify Parallelogram Law

$$W_3 = \sqrt{W_1^2 + W_2^2 + 2W_1W_2 \cos\theta}$$

Verify the relation in each individual case.

Let the mass of the scale pan carrying load $W_1 = 30{\cdot}1$ gm., that carrying $W_2 = 36{\cdot}2$ gm. and that carrying $W_3 = 47{\cdot}9$ gm. The sides of the parallelogram are drawn to the scale of 5 gm. per cm.

Results—

No of readings	Load W_1 including pan	Load W_2 including pan	Load W_3 including pan	Length OB	Length OA	Length OR	Angle BOA $\theta°$	Resultant $W_3 = \sqrt{(W_1^2+W_2^2+2W_1W_2\cos\theta)}$
	gm.	gm.	gm.	cm.	cm.	cm.	deg.	
1	30·1	36·2	47·9	6·0	5·3	8·6	88°	
2	...	...	...	...	...	...	...	
3	...	...	...	...	...	...	...	
4	...	...	...	...	...	...	...	
5	...	...	...	...	...	...	...	

Discussion—A source of error in this experiment is due to small friction of the pulleys. This error is less and less as lighter pulleys with ball-bearing arrangement are used.

The ring to which the strings are knotted should be very smooth and knots should be very loose ; otherwise directions of the strings will not be passing through one point and the parallelogram law can not be verified. The accuracy with which a load in pounds or a length in inches can be read depends upon the unit chosen.

Moment of a Force

When a body can turn about a certain axis, the effect of a force to rotate it is found to depend upon two factors,—(1) the magnitude of the force and (2) the perpendicular distance of its line of action from the axis of rotation of the body. The algebraic product of the force and the perpendicular distance of its line of action from the axis of rotation is called the **moment** of the force. If the rotation is *anti-clockwise* the moment is taken to be positive, and if it is clockwise the moment is taken to be negative.

If two or more coplanar forces acting upon a rigid body produce equilibrium, the algebraic sum of the moments of all the forces about *any point* in the plane is zero. Hence, if two forces acting upon a body, capable of rotation about an axis, produce equilibrium, the moments of the two forces about the axis are equal and opposite. This is called the *Law of Moments*.

Forces, whose lines of action are parallel, are termed *parallel forces* Two parallel forces acting in the same direction are said to be *like* and those acting in opposite directions are said to be *unlike* parallel forces. Two unlike parallel forces, if equal in magnitude, are called a *couple*. The effect of the couple upon a body is to tend to rotate it continuously about a given axis.

Date—

Experiment 15

To Verify the Law of Moments

Theory—If two forces acting upon a rigid body, which is capable of rotation about an axis, keep it in equilibrium, then the moments of the forces about the axis are equal and opposite.

Apparatus—The moment apparatus, two weight hangers, a few slotted weights each of 0·1 lb mass, and a spirit level.

A moment apparatus consists of a long and graduated uniform rectangular rod SS (Fig 53) suspended horizontally at its middle

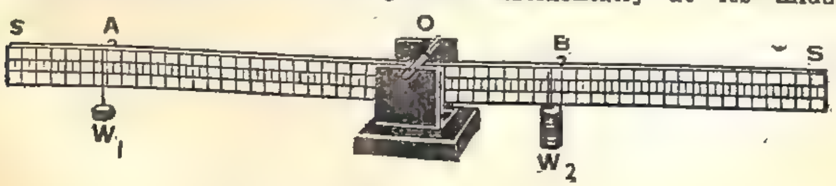


Fig. 53—To verify Law of Moments

point O by a little cross-bar from two vertical pillars. To have small friction at the points of support the lower edge of the cross-

bar is made sharp. A spirit level is placed on the bar and a small weight is counterpoised on the other side to maintain the horizontality of the bar. Two scale pans A and B each having a hook, can be placed anywhere on the rod.

Procedure—Place a spirit level on the edge of the bar along its length as near to the centre as possible. Take two scale pans or weight hangers and weigh them separately in a balance Let their weights be W_1 and W_2 lbs. Suspend the scale pans by hooks from the graduated rod. Place a load of one or two pounds on one pan and a different load on the other. Keep one hanger fixed and slide the other over the rod until the bar becomes horizontal; its horizontal position being tested with the spirit level. Take three readings with the same pair of loads, in which the position of one load may be kept fixed. Take three or four such pairs of loads and tabulate the readings as shown. If W_1 is the total load including the weight of the hook or the pan at A and W_2 that at B and if OA and OB are the distances of the hooks from the point of support, then it would be found that $W_1 \times OA = W_2 \times OB$.

Results—

Weight of scale pan at A = 0·1 lb. say.

Weight of scale pan at B = 0·1 lb. say.

No. of readings	Load on Pan at A	Total load at A	Distance of A from O	Moment of W_1 = Force × Distance	Load on Pan at B	Total load at B	Distance of B from O	Moment of W_2 = Force × Distance
	lb.	lb.	in.	lb. × in.	lb.	lb.	in.	lb. × in.
1	0·5	0·6	15·0	9·0	0·7	0·8	11·2	8·96
2	0·4	0·5	18·5	9·25	0·6	0.7	13·2	9·24
3	0·8	0·9	7·0	6·3	0·5	0·6	10·5	6·3
4	0·1	0·2	20·0	4·0	0·2	0·3	13·4	4·02
5	0·9	1·0	11·5	11·5	0·7	0·8	14·4	11·52

Discussions—The equilibrium of the suspended rod should be stable as otherwise the rod, if slightly tilted, would not come again to the horizontal position. But if stability is much increased a small load on one side would not appreciably tilt the rod and the sensitivity would be decreased affecting the accuracy of the experiment.

Since the rod is calibrated in tenths of an inch and the hook has an appreciable width, the reading for any position of the hook cannot be taken correct to a tenth of an inch. Hence there is a slight variation in the exact equality of moments for each position of equilibrium. This variation is found to be less than 1%. The ratio of the loads placed on two sides should not be too small; since then the ratio of the arms would be reciprocally too small or large. Any error in reading the length of the smaller arm would entail a larger percentage of error.

ORAL QUESTIONS

What is meant by a moment of a force? Is it possible to measure the weight of a body by the moment apparatus, how? What for is the spirit level on the bar? Is the weight of the bar of any consequence in the measurement of moment? Is it essential that the bar be suspended at its middle point? Is it possible by modifying this apparatus to demonstrate the laws of like and unlike parallel forces? What is the difference between the moment and a couple?

Date—

EXPERIMENT 16

To Verify the Laws of Parallel Forces in Equilibrium

Theory—If a body be acted upon by two or more parallel forces, the resultant force is equal in magnitude to the algebraic sum of the components and the point of application of the resultant is such that the sum of the moments of the component forces about that point would be zero.

Apparatus—A uniform and rigid wooden lath of length about 3 ft. having graduations in inches, two spring balances, a weight hanger with slotted weights.

The wooden lath PP is provided with two hooks O_1O_2 at its ends by which it may be suspended from a framework by two spring balances S and S (Fig. 54). The point of support of any hook is marked by an indicator line. The weight hanger W of a known mass has got another indicator line at which it can be suspended. Suitable loads can be mounted on the hanger.

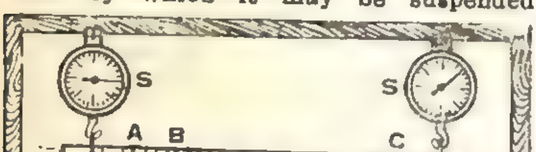


Fig. 54—Parallel Forces Apparatus

Procedure—Suspend the lath by the terminal hooks from the spring balances and take the initial readings of the pointers of the balances. The sum of the weights recorded by the balances gives the weight of the lath.

Suspend the weight at any point A of the lath and read its position on the scale attached to it. Then put a known load on the hanger and take the readings of the balances. Shift the hanger to different points on the lath as given by B and C etc. and take readings each time. The experiment is repeated with different weights on the hanger. Tabulate the results and show that for any set of observations the moments of the forces about the point of support of the weight hanger are equal.

Result—

No. of readings	Initial reading of SO_1	Final reading of SO_1	Force P_1	Distance O_1A	$P_1 \times O_1A$	Initial reading of SO_2	Final regarding SO_2	Force P_2	Distance O_2A	$P_2 \times O_2A$
	lb.	lb.	lb.	in.	lb. × in.	lb.	lb.	lb.	in.	lb. × in.
1	1·3	3·2	1·9	15·5	29·45	1·3	2·15	0·85	34·5	29·3
2	...	...	...	...	...	...	...	...	...	...
3	1·3	3·0	1·7	22·2	37·74	1·3	2·65	1·35	27 8	37·5
4	...	...	...	...	...	...	...	...	...	...

Discussions—The type of spring balances, as shown, is graduated in one-tenths of a pound and the bar in one-tenth of an inch. Hence the product of the mass and the length as found experimentally should be correct to the nearest integer. To ensure a greater uniformity of result a more sensitive type of spring balance is required.

Oral Questions

How can you define a force? What is the theorem on parallelogram of forces? Is this theorem valid when any number of forces act upon a body? What is the theorem on parallel forces? What are like and unlike parallel forces? Is it possible to co-relate the theorems of parallelogram of forces and parallel forces; if so how?

Date—

Experiment 17

To Verify Newton's Second Law of Motion

Theory—The rate of change of momentum is proportional to the impressed force and takes place in the direction of the straight line along which the force acts. Hence force is the product of mass and its acc. leration, or in other words, a given externally impressed force always produces a constant acceleration on a mass free to move. If the mass starts from rest and is under a constant acceleration f for a time t, the space s traversed is given by,—

$s=\frac{1}{2}t^2f$ or $\frac{s}{t^2}=$constant, since f here is kept constant.

Apparatus—An Atwood's machine, two equal loads suspended by a light string, a metronome or a stop-watch.

An Atwood's machine consists of a straight and stout metal scale, 2 to 4 metres in length, fixed accurately vertical to a rigid

support (Fig. 55). The top of the scale carries a pulley W which can turn very freely without friction. The fine string, carrying two equal loads P and Q at the ends, passes over the pulley. A small additional load R called the *rider* as shown separately in the figure may be mounted on any one of the loads to make it a bit heavier and to impart a motion to the system. C is a platform on which the load P can be supported and by a mechanism this support may be removed and load released at a known instant. In an improved form of the apparatus the platform C is dispensed with and the load P made of iron may be clutched by an electromagnet M (Fig. 55 *b*). and when the current of the electro-magnet is switched off at a known instant, P is released. B is a ring vertically below C and is large enough to allow P to pass through but it arrests the load R. as shown in Fig. 55 (*b*). A is another platform which stops the motion of P farther down. All the platforms can be adjusted at desired heights.

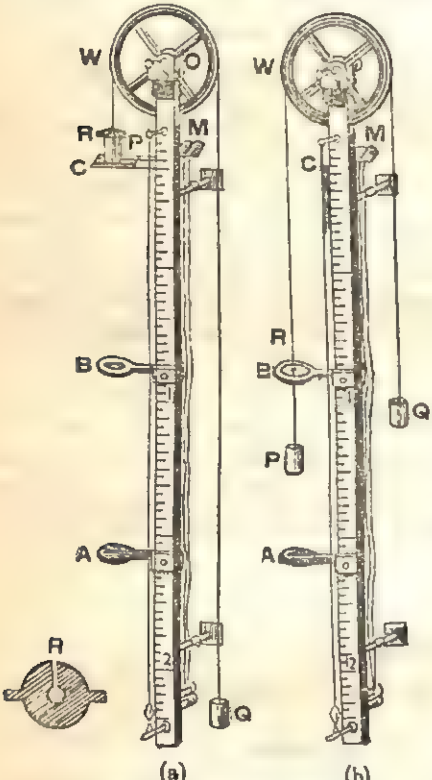


Fig.—55 Atwood's Machine

Procedure—Remove the ring B from the stand. Place the rider R upon the load P and hold the combination by the electro-magnetic clutch or by any other means as available. Raise the platform A and clamp it at about 1 metre below the load P. Measure the distance from the lower end of P to the upper surface of A accurately with a metre scale at least three times and find their mean value ; call it s.

Take a stop-watch measuring one-tenth of a second. Simultaneously switch off the current of the electro-magnet and start the watch. The load P with R is found to descend with an acceleration. Just when P touches the plate A, you get a sound and instantaneously stop the watch. Note the interval t. An accurate reading of such a short interval requires some preliminary practice. Students are recommended to practise such a recording of interval a number of times before taking actual readings.

In this way take a number of readings by varying the distance of s to about 1·5, 2, 2·5 metres and record corresponding times of fall. It would be found that that ratio of s and t^2 in every case is very nearly constant. Hence, a given force produces a constant acceleration upon a given mass.

Results—

No. of readings	Space moved s cm.	Time required t sec.	$\frac{s}{t^2}$ cm./sec^2	mean $\frac{s}{t^2}$ cm./sec^2	$f=\frac{2s}{t^2}$ cm./sec^2
1	150·2	5·8	4·50		
2	200	...	4·51		
3	251	7·5	...	4·52	9·04
4	302	8·2	4·51		
5	348	...	4·58		

Discussions—The approximate constancy of the ratio s/t^2 shows the uniformity of acceleration produced by the weight of the rider. It is a matter of difficulty to reckon the interval when the system is moving with a high speed. The variation of observed s/t^2 may be due to this as also to some frictional forces called into play at the pulley.

Measurement of g with an Atwood's Machine

To measure the acceleration due to gravity at the laboratory, a similar experiment with an Atwood's machine is made and the acceleration f of the system is carefully determined. If the total mass moved be M and the moving force be mg, then

$f=\frac{mg}{M}$ where $g=\frac{Mf}{m}$ in whatever units they are expressed.

In the particular experiment, combined masses of P and Q with connected string $=2183·6$ gm. Mass of R $=20·4$ gm. Hence total mass $=2204$ gm. Taking $f=9·04$ cm./sec^2.

$$g=\frac{2204\times 9·04}{20·4} \text{ cm./sec.}^2=995 \text{ cm./sec.}^2$$

This method of measuring g cannot be very accurate, since a small error in measuring t will cause an appreciable percentage of error in determining f, since the general values of t should be kept small for experimental facilities. This variation causes a proportionate variation in the observed value of g.

Verification of Equations of Motion

The equations of motion of bodies, based upon Newton's first and second laws of motion, are the following :—

(1) $v=u+ft$.
(2) $s=ut+\frac{1}{2}ft^2$.
(3) $v^2=u^2+2fs$.

where u=initial velocity, v=final velocity, f=a constant acceleration, t=time during which acceleration acts and s=space traversed during the period t.

In particular cases when the body starts from rest, $u=0$ and the equations of motion reduce to the forms, $v=ft$., $s=\frac{1}{2}ft^2$ and $v^2=2fs$.

To verify the first equation, *i.e.*, $v=ft.$, take two equal loads P and Q suspended by a light string and suspend the loads by the string passing over the pulley W of the Atwood's machine. Fix up the ring B and platforms A and C at their usual positions. Mount the load P on C and put the riders R on P. Measure the distance AB. Release P with R and simultaneously start the watch and observe the time required for the rider to come upon B. Let the time interval be t. Again measure the time for the load P to travel the distance AB, which is, say, T. Since the load moves over AB with a uniform velocity, v is AB/T. The period during which the system is under acceleration is t. Change the distance AB a number of times and in each case measure t, AB and T It will be found that AB/T is proportional to t; or in other words, $v \propto t$.

or, $\frac{v}{t}$ = constant $=f=$ acceleration produced by the weight of the rider.

To verify the second equation, $s=\frac{1}{2}ft.^2$ make an experimental arrangement as that of Expt. 17, and show that $2s/t^2=$ constant.

Hence $\frac{2s}{t^2}$ = constant $=f=$ acceleration produced by the weight of the rider.

To verify the third equation, $v^2=2\,fs.$, proceed as that of the first law and measure in each case $v=$ AB/T and also measure BC which is s. Then, show that $v^2 \propto s$.

Hence $\frac{v^2}{2s}$ = const. $=f=$ acceleration produced by the weight of the rider. In this case we assume that the distance of fall is such that there is no variation in the weight of the rider. This is actually so for small heights.

In all these cases, accurate verification is not so easy as they appear, because of the difficulty in measuring such short intervals of time. For this reason, a synchronous method of reckoning time by a metronome is sometimes adopted. In an improved form of Atwood's machine, in which the string carrying the loads is replaced by a paper tape and time is recorded by a vibrator marking short intervals with ink on the tape, such difficulties have been overcome. (For details *vide* Basu & Chatterjee's Intermediate Physics.)

Date—

EXPERIMENT 18

To Verify Newton's Third Law of Motion

Theory—To every action there is an equal and opposite reaction. This principle when applied to two bodies undergoing collision would be equal to the same even after collision. This is known as the principle of conservation of momentum.

Apparatus—A ballistic balance, a few balls of steel of different sizes, metre scale, vernier callipers and a physical balance with accessories.

A simple ballistic balance consists of a heavy and rigid vertical support T provided with an adjustable clamp C (Fig. 56). The clamp carries a cross-piece. The ends of the cross-piece are provided with two identical blocks BB. Two steel balls M and m are suspended from these blocks: each one being fastened by two threads going to the blocks through small holes drilled in metal strips. The ends of the threads are wound over small wooden cylinders fixed upon each block. The wooden cylinders may be rotated and thereby the length of the thread may be adjusted. This sort of suspending anything is known as a bifilar suspension and is mostly used when oscillation of any body in a definite plane is desired: further there is no rotation of the body along vertical axis while oscillating. A metre scale S is fixed horizontally to read the extent of swing. An electromagnet E is used to clutch any ball at any position. On switching off the current the ball is released by the magnet and it would strike the other ball. When collision of both the balls in motion is desired, two such electromagnets may be used on both ends of the scale.

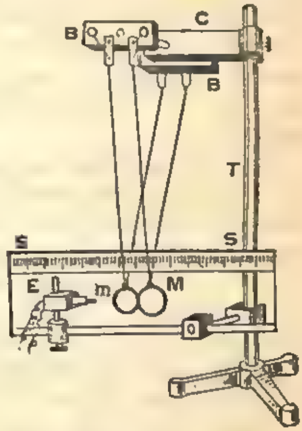


Fig. 56—Ballistic Pendulum

Procedure—Weigh the two balls separately in a balance. Let their masses be M and m, M being larger than m. Measure the diameters of the balls with a screw gauge. Take three readings of diameter for each ball with a vernier callipers and find their mean value. Let the mean values of diameters be D and d.

Suspend each ball from the cross-piece by a bifilar method such that the *centres of the two balls are on a horizontal plane.* Place the scale S so as to coincide with the plane of oscillation of both the balls. Pass a fine string through the holes of the strips carrying the bifilar suspension. Measure the vertical distance from the middle part of this string to the upper surface of the ball either with a metre scale or better with a cathetometer. Take three to four such readings and find the mean. The mean of these plus the radius of a ball gives the equivalent length of a pendulum, which is, say d

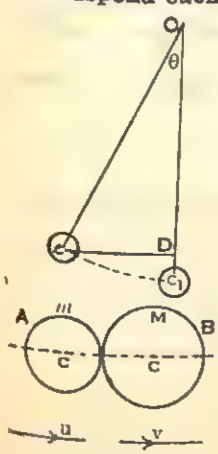


Fig. 57

Adjust the position of the strips so that the balls just touch each other. Take the reading of the position of the string from a direction perpendicular to the scale. Care is taken to see that for normal positions of the balls, they just touch each other. Measure the vertical distance between the horizontal thread line at the top and the upper surface of the scale. Let it be d (Fig. 57)

Now displace one ball, say larger one, so as to touch the electromagnet and pass the electric current so as just to clutch this ball. Read the position of the displaced thread on the scale whence the horizontal displacement of the thread is found. Let it be x, which should be small. If angular displacement of the pendulum be θ_1 then $\tan\theta_1 = x/d$. Thus knowing x and d and referring to a Tan-table, θ_1 is found.

Switch off the electromagnet when the ball takes a start and as it reaches the vertical position, it collides with the smaller ball and both are set into motion. Read the extents of swings of strings attached to the balls from the scale. This can be done once by watching the smaller ball as it swings and in the next experiment the bigger one. Take a number of readings for the swings of both the balls. Let the scale readings for the bigger and smaller balls when thrown by impact be y and z. Then $\tan\theta_2 = y/d$ also $\tan\theta_3 = z/d$, whence θ_2 and θ_3 are found.

Now if h_1 be the height through which the bigger ball was raised when it was clutched by the electromagnet, the potential energy at this position is Mgh_1. Just before collision let its velocity be u_1. Since at this position energy is all kinetic, its value is $\frac{1}{2}Mu_1^2$.

$\therefore \quad \frac{1}{2}Mu_1^2 = Mgh_1$ whence $u_1 = \sqrt{2gh_1}$ *

again, $h_1 = l(1-\cos\theta_1) = 2l\sin^2\left(\frac{\theta_1}{2}\right)$

$$\therefore \quad u_1 = 2\sqrt{gl}\sin\frac{\theta_1}{2}$$

Hence, the momentum of the bigger ball before impact is

$$Mu_1 = 2M\sqrt{gl}\sin\frac{\theta_1}{2}$$

In a similar way the momentum of the bigger ball after impact $= Mu_2 = 2M\sqrt{gl}\sin\frac{\theta_2}{2}$ and of the smaller ball $= mu_3$ $= 2m\sqrt{gl}\sin\frac{\theta_3}{2}$

Hence, if the principle of conservation of momentum be true, $Mu_1 = Mu_2 + mu_3$

$$\text{or,}\quad M\sin\frac{\theta_1}{2} = M\sin\frac{\theta_2}{2} + m\sin\frac{\theta_3}{2}$$

Results—

The mass of bigger steel ball = 13·8 gm.
The mass of smaller steel ball = 9·42 gm.

---

*The rotational energy for small oscillations is very small and hence, it may be neglected.

The vertical distance from the axis of suspension to the upper edge of the scale = 60·4 cm.

No. of readings	Displacement of M cm.	M sin $\frac{\theta_1}{2}$ gm.	Swing of M cm.	M sin $\frac{\theta_2}{2}$ gm.	Swing of m cm.	m sin $\frac{\theta_3}{2}$ gm.	M sin $\frac{\theta_2}{2}$ + m sin $\frac{\theta_3}{2}$	Percentage difference
1	8·5	·966	3·0	·276	8·4	·681	·957	1%
2	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...

Discussions—The instantaneous reading of the extent of swing of a ball after impact is a matter of practice and it is really the source of error in this experiment. The collision should be accurately *head-on*, as otherwise the motion of the balls will not be in the same vertical plane after impact. The loss of energy due to friction at the supports, generation of heat due to elastic deformation at collision and production of sound etc. is supposed negligibly small.

Oral Questions

What are Newton's laws of motion? How does the idea of force come from these laws? Define a unit of force. What is momentum and how is momentum related with the impressed force? How is the idea of mass derived from the effect of the force acting upon it? How is the principle of conservation of momentum related with Newton's third law? What is free motion of a body? The impact of material bodies in vacuum is the simplest practical application of Newton's third law; can you cite an example of the above statement? Clearly differentiate between the cases where we apply force as defined by Newton's second law and as defined by the third law.

Friction

If an arrangement is made such that two bodies always remain in contact, a small force acting on one body parallel to the surface of contact may not move it relative to the other. The reason is that as an soon as external force is applied to one body, an equal and opposite force is produced on it at the point of contact due to the other body. When, however, the external impressed force is gradually increased, this retarding force increases to a certain extent and then assumes a steady value. Any further increase in the impressed force will actually move the body. Such a force which arises out of bodies in contact is called friction. When one body is just on the point of sliding over the other, the friction is said to be limiting, whereas if the body is actually sliding over the other, the friction is said to be kinetic or dynamic [*Vide* Basu and Chatterjee's Intermediate Physics, Part I, Chap. V].

Laws of Limiting Friction—The direction of the limiting frictional force is opposite to the direction in which the force tending to move the body acts.

(*a*) The magnitude of the limiting friction always bears a constant ratio to the normal reaction. The ratio of limiting friction to the normal reaction is called the co-efficient of friction.

(*b*) The constant ratio depends only on the material and nature of the surfaces in contact but not the area or shape of the surfaces.

Date— EXPERIMENT 19

To Determine the Coefficient of Limiting Friction between two substances on a Horizontal Surface

Theory—The ratio of the limiting friction to the normal reaction across two surfaces is called the coefficient of friction and is usually denoted by μ. Thus, if F be the limiting friction and R the normal reaction, then

$$\mu = \frac{F}{R}$$

μ depends upon the nature of materials in contact but not upon their areas or shapes provided normal reaction does not change.

Apparatus—A horizontal friction board, a number of rectangular blocks of various materials with plane bases, a scale pan, several weights.

A friction board consists of smooth wooden table T which can be made horizontal (Fig. 58). A light pulley P is fixed at one end. Bodies B and C in the form of rectangular blocks, between which the coefficient of friction is to be determined, can be placed on the table one above the other. A string, one end of which is attached to the top-most block, passes horizontally over the pulley and its other end carries a scale pan on which weight W can be placed. If necessary, extra loads L can be placed upon the rectangular blocks.

Fig. 58—Horizontal Friction Board

Procedure—To determine the coefficient of friction between any two materials, say metal and wood, take two rectangular blocks one of brass B and the other of wood C and make their surfaces of contact clean and dry. Find the mass of the block C in a rough balance. Let it be M gm. Attach a string with C and pass it over the pulley and tie it to a scale pan. The string must remain horizontal upto the distance of the pulley. Then place a spirit level upon B and by means of levelling screws at the base of T (not shown in the diagram), make the upper surface of B horizontal.

Weigh the scale pan; let the weight be m. Next place a load L on the block C and place weights, one by one, on the pan till the block is *on the point of starting.* Note the total load F on the pan. Repeat observations for every load on the block. Take three to five such loads on the block and tabulate readings as given below.

Results—

The mass of the wooden block = 292·3 gm.
The mass of the scale pan = 100·1 gm.

Surfaces in contact	No of readings	Load L on Block C	Normal Reaction R=M+L	Load W on Scale pan	Pulling Force F=m+W	Coefficient of Friction F/R	Mean value of Coefficient
		gm.	gm.	gm.	gm.		
Wood and Metal	1	500	792·3	40	140·1	0·18	0·15
	2	600	892·3	43	143·1	0·16	
	3	800	1092·3	60	160·1	0·15	
	4	900	1192·3	75	175·1	0·13	
	5	1000	1292·3	83	183·1	0·15	

Discussions—The coefficient of friction depends upon the surface conditions such as moisture, lubrication and the position of the surface fibres, if any, etc For this reason it is not possible to supply an exact value of the coefficient for any two substances.

The friction board, while under experiment, should always be kept horizontal; otherwise the normal reaction R is not equal to the combined masses of the block and the weights placed upon it. The string passing over the friction table should also be horizontal, otherwise the masses of the scale pan and the weights placed upon it would not be equal to the frictional forces.

Verification of Laws of Limiting Friction—To verify the first law take any two substances in form of blocks and place them on the friction board. Then carry on with the experiment in the preceding manner. It would be found that the ratio of the limiting friction and the normal reaction is a constant quantity.

To verify the first half of the second law, take different pairs of substances and find their coefficients of friction. It would be found that values of the coefficients are different for different pairs. Again for any pair, if the nature of the surfaces in contact be modified by lubricating or polishing, the magnitude of the limiting friction would change.

To verify the second half of the second law, find the coefficient of friction for any pair. Then cut the upper block so as to reduce the size of the surface in contact and find the coefficient again. It would be observed that the result does not change appreciably.

Date—

EXPERIMENT 20

To Determine the Coefficient of Limiting Friction by Inclined Plane Method

Theory—If a body rests on a plane surface, capable of being inclined, and if α be the angle of inclination of the surface with the horizontal plane when the body is just on the point of sliding down, then the coefficient of limiting friction between the substances is $\mu = \tan \alpha$ (*Vide* Basu & Chatterjee's Physics, Part I, Chap. V)

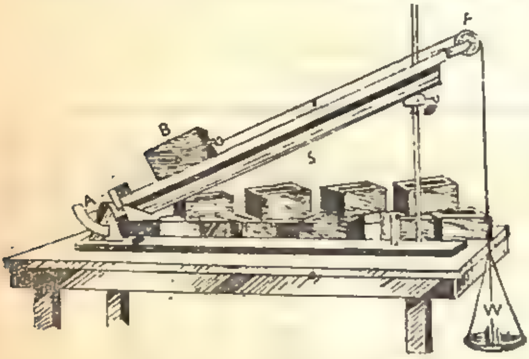


Fig. 59—Inclined Plane

Apparatus—An adjustable inclined plane, a block of wood, a scale pan and some weights.

An inclined plane apparatus consists of a horizontal base board provided with a rigid vertical rod (Fig, 59). Another rectangular board S is hinged at A at one end of the base board such that it can be placed at various angles with the base by clamping it anywhere on the vertical rod. The angle of inclination can be read directly by a pointer moving over a circular scale A. Blocks of various substances are provided and plane sheets of various materials can be fixed upon the inclined plane.

A smooth pulley P is fixed at one end of the board and if necessary, a block B can be pulled up by a load W when attached to it by a cord running over the pulley. The attachment is not necessary so far as this experiment is concerned.

Procedure—To determine the coefficient of friction between, say wood and wood, place a plane sheet of wood on the inclined plane and put a wooden block upon it. Make the base board horizontal with a spirit level. Loosen the clamp on the vertical rod and raise this end slowly till the block is on the point of moving down. Read the angle of inclination from the scale. Again, make the angle smaller and bring the block to the central part and lift the plane to another angle for which the block just starts to move. In this way take a number of readings for different loads on the block and find the mean, The tangent of this angle is equal to the coefficient of friction.

An alternative method of directly getting the tangent of the angle is to measure with a metre scale the height of the upper surface of the plane from the base board along the vertical rod and also to measure the distance from the foot of the rod to a point on the base board where the upper surface of the inclined plane is

likely to meet. If the former is h and latter is x, then $\tan \alpha = h/x$. Take a number of readings for both h and x and find their mean ratio.

Results—

Surfaces in contact	No. of readings	Height h cm.	Length of base board x cm.	Value of μ $= \frac{h}{x}$	Mean value of μ
Wood and Wood	1	28·8	80	·36	·38
	2	...	...	—	
	3	30·4	...	·38	
	4		...	...	
	5	30·8	...	·38	

Discussions—The coefficient of friction varies slightly for different regions of the inclined plane. Hence, when the block is made to start from different parts of the plane for different sets of observations, the value of μ would be found to vary slightly. Hence a very good accuracy of result cannot be claimed in such an experiment.

ORAL QUESTIONS

What do you mean by friction? What is the coefficient of friction? Define laws of limiting friction. What is the relation between the coefficient of friction and normal reaction? Can you suggest any means of reducing the friction between two bodies? Does the coefficient of friction depend on the area of contact of two bodies?

Elasticity and Hooke's Law

A material body may be deformed by the application of external forces. A deformed body is said to be in a state of strain. When the body is strained, internal forces are called into play, which tend to bring back the body to the original state. The internal forces are called stress. Hooke's Law states that whatever may be the nature of the strain, the stress produced in a body is in direct proportion to the strain produced in it. The ratio of stress and strain is called the *coefficient of elasticity*.

The nature of the strain varies with the nature of the applied stress. When a body is subject to a uniform pressure all over it, the nature of the stress is called *volume stress*. As a consequence the body undergoes a *change in volume*. The change in volume per unit volume is called the *volume strain* and the ratio of these two measures the coefficient of volume elasticity or simply *bulk modulus*. When the body is such that forces acting *tangentially* across its opposite surfaces *deform its shape*, the force per unit area is called the *shearing stress* The deformation, measured by the relative

displacement of planes at unit distance, is called the *shearing strain.* The ratio of these is called the *modulus of rigidity.*

If a body, whose length is very large in comparison to its breadth or thickness, is acted upon by two equal and opposite forces along its length such that there is an increment in length only, the change in other dimensions being negligibly small, the stress acting upon it is called *tensile stress.* It is measured by the force acting perpendicularly per unit area of cross-section. The elongation per unit length is called the *tensile strain.* The ratio of the tensile stress and tensile strain is called **Young's modulus** of elasticity. Suitable bodies for determining Young's Modulus are samples of metal wires, thin rods etc. [For a detailed study of elasticity *vide* Basu & Chatterjee's Intermediate Physics, Part I, Chap. IX.]

Date— EXPERIMENT 21

To Determine Young's Modulus for a Wire by Vernier Method

Theory—If a load of M gm. attached to the end of a uniform wire of radius r cm. and of length L cm. stretches it by an amount l cm. within its limit of elasticity, then Young's modulus Y of the *material* of the wire is given by the equation,

$$Y=\frac{\text{Tensile stress}}{\text{Tensile strain}}=\frac{Mg/\pi r^2}{l/L}=\frac{MgL}{\pi r^2 l} \text{ dynes/sq. cm.}$$

where g = acceleration due to gravity at the place of experiment.

Apparatus—Young's Modulus apparatus with vernier attachment, measuring tape or rod, a scale pan or a weight hanger and a few known loads.

The apparatus consists of three long pieces of wires of the same material rigidly suspended from a beam B, (Fig. 60*a*). One of the side-wires carries a millimetre scale S and the other side wire is attached to a similar piece which is generally not graduated. The purpose of this piece is simply for balancing the wires. A load W suspended from both the pieces, keeps these wires stretched free from any kink. The experimental wire E, hanging at the middle, carries a vernier scale V which can slide up and down the groove between vertical side pieces. The lower end of the vernier is attached to a scale pan P by a piece of wire passing freely through a circular hole in W. Some apparatus is provided with only two pieces of wires,—one carrying the main scale S and the other carrying the vernier scale V (Fig. 60 *b*).

Procedure—Place a load of 1 or 2 kilograms on the scale pan to make the experimental wire straight. This is called the 'dead load'. Measure the diameter of this wire at three or four points by a screw gauge and at each point take two readings at right angles to each other. This gives the mean diameter from which

find the area of cross-section of the wire in *sq. cm.** Then find from the Table of Physical Constants or enquire from the teacher in charge the value of the breaking stress † for the particular specimen. Multiply the area of cross-section of the wire by the breaking stress, whice gives the *breaking load* for the wire. The product gives the value of a load which when put on the scale pan would stretch the given wire beyond its limit of elasticity.

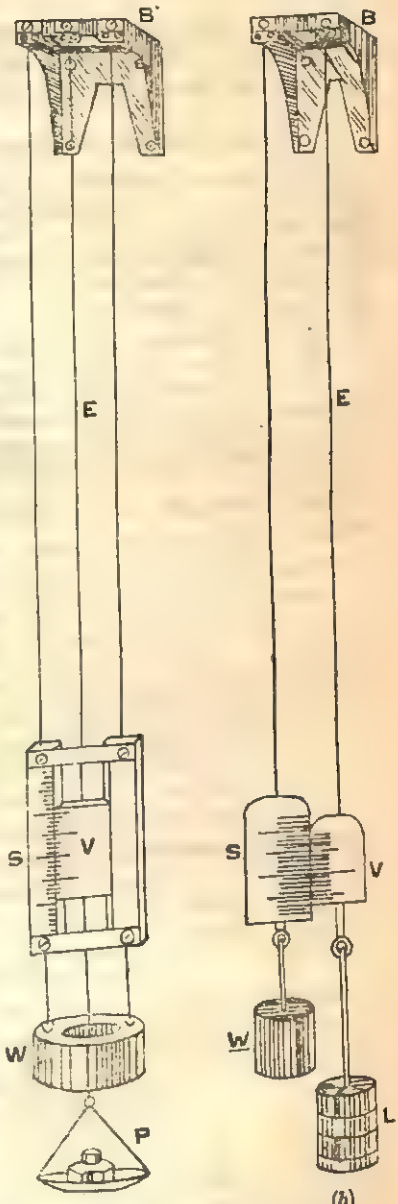


Fig. 60—Young's Modulus Apparatus

Next measure the length of the experimental wire from the point of suspension to the upper end of the vernier with the measuring tape. If the point of suspension of the wire is too high to reach directly, an wooden lath of a measured length may be used to find the length of the wire to the nearest centimetre or inch.

Take the reading of the vernier with a *dead* load of one or two kilogrames on the scale pan. Then put a load of one or half kilogramme on the pan whereby the wire is slightly elongated. Wait about a minute and take the vernier reading again. In this way add each time an equal load and take the corresponding reading of the vernier, waiting about a minute after adding the load ; care being taken that the *total load on the pan does not exceed half the breaking load* as calculated previously. After the maximum load is reached, take out the weights one by one from the pan and record another series of readings for decreasing loads up to the dead load. Tabulate the observations and thence calculate Young's modulus for the specimen of the wire.

* Area of cross-section $= \pi r^2 = 3{\cdot}14 \times r^2$. The purpose of taking readings of diameter at right angles is that the wire gets sometimes flattened at some parts due to the defect in construction or continued use.

† The breaking stress for a particular material is defined to be the load just sufficient to strain a wire of that material of unit cross-section beyond the elastic limit producing a permanent set.

Results—

(1) To measure the diameter of the experimental wire.
Number of divisions on the micrometer screw head = 50, say
Pitch of the micrometer screw = 0·5 mm.

$\therefore$ Least count of the screw gauge $= \frac{\cdot 5}{50} = 0\cdot01$ mm. $= 0\cdot001$ cm.

No. of observations	Readings at		Mean value	Instrumental error	Corrected Diameter
	at a position	at right ∠s			
	mm	mm	mm	mm	mm
1.	0·5+0·29=0·79	0·5+0·28=0·78			
2.	0·5+0·30=0·80	0·5+0·29=0·79	0·79	+0·02	0·81
3.	0·5+0·29=0·79	0·5+0·30=0·80			

$\therefore$ Radius of the wire $= \frac{0\cdot81}{2} = 0\cdot405$ mm. $= 0\cdot0405$ cm.

The material of the wire is, say, steel the breaking stress for which is 8000 kg. per sq. cm. (*vide* Table after this experiment).

Thus the breaking load for this specimen wire
$= \pi \times (0\cdot0405)^2 \times 8000$ kg. $= 40\cdot32$ kg.
$\therefore$ Maximum permissible load on the pan is nearly 20 kg.

(2) Measurement of Elongation of the wire :—50 div. of vernier of the apparatus = 49 div. of main scale
or. $1m - 1v = \frac{1}{50} = \cdot02$ of a main scale division.
Main scale graduated in millimetres (say)
$\therefore$ Least count of vernier $= \frac{1}{50}$ mm. $= 0\cdot02$ mm.
Initial load on the wire = 2 kg. (Dead Load)

No. of observations	Loads added	Scale & Vernier Readings		Mean	*Elongation for 3 kg.	Mean Elongation for one kg.
		Loads Increasing	Loads Decreasing			
	kg.	mm.	mm.	mm.	mm.	mm.
1	0	18·02	18·02	18·02		
2	1	18·32	18·34	18·33		
3	2	18·62	18·64	18·64		
4	3	18·96	18·98	18·97	0·95	0·307
5	4	19·24	19·26	19·25	0·91	
6	5	19·56	19·56	19·56	0·92	= ·03 cm.

* To get these figures, see the columns "Loads added" and "Mean." Corresponding to zero load, the reading is 18·02 mm. and corresponding to 3 kg. load, the reading is 18·97 mm. Subtract the second reading from the 1st. The difference is 18·97 − 18·02 = ·95 mm. for a difference of load of 3 kg. Similarly subtract c 2nd observation from the 5th and so on.

Length of the wire = 289 cm. say.

The Young's modulus Y for the specimen is, therefore.

$$= \frac{1000 \times 981 \times 212}{3{\cdot}14 \times ({\cdot}0405)^2 \times {\cdot}03} = 2{\cdot}01 \times 10^{12} \text{ dynes/sq. cm.}$$

If the result is to be found from the graph, the last two columns of the tabulated chart are not required. Add one column after the "Mean" column with the heading "*Elongations*". Now subtract the reading 18·02 from 18·33 which gives ·31 mm. as the elongation for 1 kg. and record it in line with the reading 18·33. Again subtract 18·02 from the 3rd reading 18·60, which gives ·61 mm. as the elongation for 2 kg. and record it in line with 18·64. In this way subtract the 1st reading always from the subsequent readings and get the elongations for higher loads.

Take the increasing load as abscissa and corresponding elongation as ordinate. The graph should show a straight line due to the fact that the elongation of the wire is proportional to the load applied (Fig. 61). Then taking any point A on the straight line

Mean	Elongations
mm.	mm.
18·02	
18·33	·31
18·64	·62
18·97	·94
19·25	1·22
19·56	1·53

Last two columns of the Table

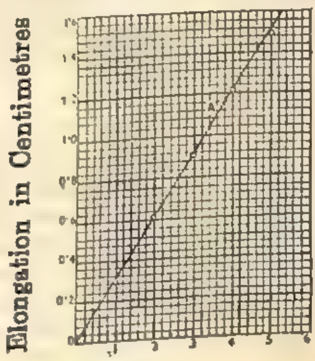


Fig. 61

obtained, find the elongation l and corresponding load Mg. Hence calculate Young's modulus.

Discussions—The wires carrying the main scale and the vernier scale must be suspended from the same support such that any disturbance of the support would equally affect both the scales and their relative position would not be altered. The wires must be of the same material and very nearly of the same length, otherwise a variation of the temperature would increase their lengths by different amounts and cause the relative position of the scales to change during the course of the experiment.

There should not be too much friction between the vernier and the main scale within the groove. Care must be taken to see that the wire is not loaded by more than half the breaking load.

ORAL QUESTIONS

Define Hooke's law and Young's modulus. Why do you take a long wire for your experiment? Does Young's modulus differ by using a thicker wire of the same material? What is the use of two wires side by side? What are the effects

if the two wires are not of the same material and are not suspended from the same support ? Why should the elongation of the wire be measured accurately ? What is meant by the breaking load for a particular specimen ? What is the effect of temperature on Young's modulus ? What are the different moduli of elasticity ?

Date— EXPERIMENT 22

To Determine Young's Modulus of a Wire by Searle's Apparatus

Theory—If a wire of length L cm. and of radius r cm. be elongated by l under a longitudinal stretching force due to a load M gm. within the limit of elasticity, then the Young's modulus Y for the material of the wire is given by

$$Y = \frac{MgL}{\pi r^2 l} \text{ dynes/cm}^2.$$

where g is acceleration due to gravity at the place of experiment.

Apparatus—Searle's apparatus, a measuring tape, metre scale, two scale pans and slotted loads and a screw gauge.

Searle's apparatus for measuring Young's modulus consists of a brass frame-work being supported by two similar wires hanging from the same support B (Fig. 62). The two rectangular parts of the framework are loosly fitted by a cross-piece C so that any one can side vertically through a small range. One end of a spirit level L rests on an arm fixed to a frame while the other end rests on a platform being supported by a micrometer screw which moves against a short linear scale S fixed at this arm. Two hooks are attached with the framework for suspending two weight hangers.

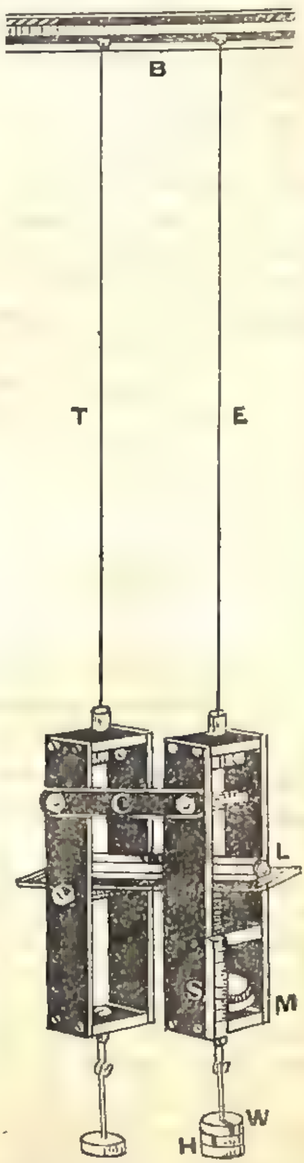


Fig. 62—Searles Apparatus

Procedure—At the start place two loads, usually 1 to 2 kg., on the hangers to make the wires straight. Measure the diameter of the experimental wire E with a screw gague at four or five different regions and at each region take readings at right angles to each other. Get the mean diameter of the wire and hence calculate the area of cross-section of the wire in *sq. cm.*

To find the breaking load for the particular sample of wire, multiply the area of cross-section of the wire in sq. cm. by the

breaking stress for the particular material. During the course of experiment, the wire should never be loaded with more than half the breaking load.

To find the least count of the micrometer attached to the frame examine the vertical scale and determine the value of the smallest division of this scale. Now give the circular scale a *complete turn* and observe the linear distance through which the edge of the disc moves; this distance gives the pitch of the screw. The pitch divided by the number of circular divisions gives the least count of the micrometer. Next level the spirit level by adjusting the mirometer screw taking care to rotate the screw in the same direction and take the initial reading. Then place a suitable load of one or half a kilogramme upon the scale pan attached to the experimental wire, and after waiting for one or two minutes level the spirit level and take a reading. In this way put equal loads by a few instalments and take correspondig readings. This gives a set of readings corresponding to loads increasing on the wire.

After the maximum load is reached, take out the weights one by one from the pan and record another set of readings for loads decreasing. Each time after loading or unloading the wire, reading must be taken after waiting for one or two minutes. Tabulate the observations. Finally, measure the length of the experimental wire from the point of suspension to the upper point of the frame with the measuring rod. Also draw the load-elongation graph as explained in the preceeding experiment and thence calculate Y.

Results—

(1) To determine the diameter of the experimental wire,—

No. of divisions on the micrometer head = 100 say

Pitch of the micrometer screw = 1 mm.

∴ Least count of the screw gague = ·01 mm.

Mean diameter of the experimental wire = 1·11 mm.

No. of obser-vations	Reading at		Mean Value	Instru-mental Error	Corrected Dia-meter
	at a position	at right ∠			
	mm	mm.	mm.	mm.	mm.
1 2 3	1·20 1·22 ...	1·23 ... 1·21	1·21	+0·03	1·18

∴ Radius of the wire $= \frac{1 \cdot 18}{2} = \cdot 59$ mm. = ·059 cm.

A brass wire is supplied, the breaking stress for which is 3000 kg. per sq. cm. Thus the breaking load for the specimen $= \pi \times {}^{\cdot}059^2 \times 3000$ kg. $= 31{\cdot}62$ kg.

Hence maximum permissible load on the pan = 15 kg. nearly.

(2) To determine the elongation of the wire for successive increment of loads.

No. of divisions on the micrometer head = 100 say
Pitch of the micrometer screw = 1 mm.
∴ Least count of the micrometer = ·01 mm.
Dead Load on the wire = 2 kg.

No. of readings	Loads added	Micrometer Readings		Mean	Elongation for 4 kg.	Mean Elongation for 1 kg.
		Load increasing	Load decreasing			
	kg.	mm.	mm.	mm.	mm.	mm
1	0	2·91	2·90	2·91		
2	1	3·20	3·21	3·21		
3	2	3·50	3·50	3·51		
4	3	3·80	3·80	3·80		
5	4	4·10	4·10	4·10	1·19	·30
6	5	...	...	...	1·20	
7	6	...	...	...	1·10	
8	7	...	...	...	1·10	

Length of the wire = 321 cm.

Thus $Y = \dfrac{1000 \times 981 \times 321}{3{\cdot}14 \times {}^{\cdot}059 \times {}^{\cdot}059 \times {}^{\cdot}03}$ dynes/cm²

Log. Calculations :

log 1000 = 3·0000
log 981 = 2·9917
log 321 = 2·5065

8·4982

log 3·14 = ·4969
log ·059 = $\bar{2}$·7709
log ·059 = $\bar{2}$·7709
log ·03 = $\bar{2}$·4771

$\bar{4}$·5158

∵ log Y = 8·4982 − $\bar{4}$·5158 = 11·9834
or, Y = antilog 11·9834 = 9·625 × 10¹¹

Such calculations are to be shown on the left hand page.

∴ Young's modulus Y for the specimen $= 9{\cdot}6 \times 10^{11}$ dynes per sq. cm.

Usually a graphical representation of the load-elongation relation is wanted in this experiment. The readings for the load added is obtained from the second column of the table. Write the top of the sixth column as "Elongation" only. Then look to the fifth column for mean readings and subtract 2·91 from 3·21 which gives 0·30 mm. or ·03 cm. as the elongation for 1 kgm. Write this value

('03) against the second line. Again subtract 2'91 from 3'51 which is '06 cm. representing elongation for 2 kgm. and write this value against the third line. In this way complete the sixth column upto 7 kgm. Now draw a graph with suitable scale between load in kgm. and elongation in cms. This would be a straight line. Now take any point on this straight line and find the corresponding load and elongation. Substitute these two data in the equation for Y and calculate the result.

Discussions—The two pieces of wire should be of the same material and should be rigidly suspended from the same support. Since a micrometer screw gauge is an instrument of higher precision than an ordinary vernier, elongation can be more accurately measured with a screw gauge. Hence this method provides a greater accuracy in determining Young's modulus, other conditions remaining the same.

Date—

EXPERIMENT 23

To Determine the Modulus of Rigidity of a Wire by Statical Method

Theory—If a wire of radius r and length l be fixed rigidly at one end and subjected to a torque T at the other end producing a torsion of θ radians, then

$$T=\frac{\pi n r^4}{2l}\theta$$

where n=modulus of rigidity of the material of the wire. If the torque be applied by two identical masses M put at the ends of a tie rope coiled over a fly-wheel of diameter d, then $T=Mgd$, where g is the acceleration due to gravity. Further, if θ be measured in degrees, then

$$\theta^\circ=\frac{\pi\theta}{180} \text{ radians}$$

Substituting the value of T and reducing θ to radian and then rearranging the terms, we have

$$n=\frac{M}{\theta}\,\frac{l}{r^4}\,\frac{gd}{\pi^2}360$$

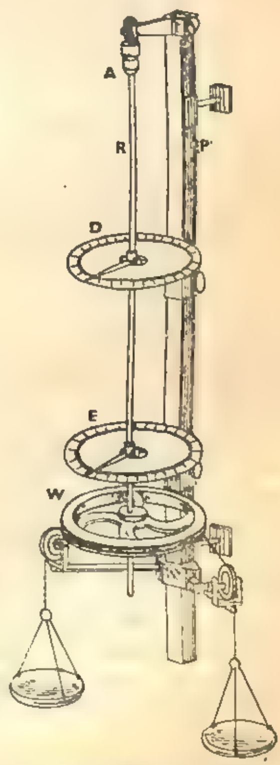


Fig. 63—Rigidity Apparatus

Apparatus—Searle's apparatus, a beam compass and a metre scale, a few identical loads and a screw gauge.

The statical apparatus consists of a stout wire R about a metre in length fixed at its upper part to a clamp. At the top of a vertical stand (Fig. 63). A suitable load is suspended at the bottom of the wire

to keep it straight. Just above the load a light fly-wheel W is rigidly clamped to the wire. Two ends of a tie rope, coiled around the fly-wheel, pass from opposite ends over two light pulleys carrying two identical scale pans. A pointer fixed with the wire at its lower part passes over a horizontal disc E graduated in degrees. In some apparatus, the wire is provided with two or three pointers at different parts of its length, each moving over a graduated disc.

Another type of rigidity apparatus is provided with a stout wire in a horizontal position. Two pointers moving over graduated scales may be clamped at any two convenient positions on the wire. Twist of the wire is effected by putting a load at the end of a tape suspended from the rim of a flywheel W placed vertically (Fig. 64).

Procedure—Measure the length of the wire between the upper clamp and the lowest pointer with a beam compass and a metre scale. Repeat the observations two or three times and get the mean value. Measure the diameter of the wire *carefully* with a micrometer screw gauge at five or six places and every where at two rectangular positions.

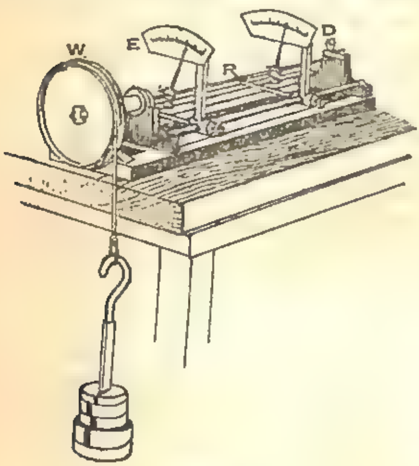


Fig. 64

Read the end of the lower pointer. Put two equal loads on the pan and read the pointers after waiting for a minute or two. Next add another two similar loads on the two pans and read the pointers. In this way take two series of readings, one for loads increasing and the other for loads decreasing. From the two series of readings find the mean twist for an applied torque or draw a graph with load as abscissa and twist as ordinate. Hence by applying the formula calculate the co-efficient of rigidity.

Results—

Length of the wire = (i)............(ii)............(iii)...............

∴ Mean Length =

Pitch of Screw gauge supplied = ...

No. of divisions on the circular head = ...

∴ Least Count = ...

Zero error of the instrument = (i)............(ii)............(iii)............

Mean zero error =

Diameter of the wire (mean of 5 different positions) =

(Tabulation for the readings of diameter may be done as shown in Expt. 21).

Diameter of the Flywheel = (i)............(ii)............(iii)............

$\therefore$ Mean diameter = ...

No. of readings	Load on each Pan gm.	Readings of Pointers			Twist Deg.	Total Twist Deg.
		Load Increasing in Deg	Load Decreasing in Deg.	Mean Deg.		
1	...	24·6	24·5	24·5		
2	10	66	65	65·8	41·0	41·1
...	...	...	...	...	...	...
...	...	...	...	...	...	...
4	60	...	...	...	...	234
...	...	...	...	...	...	
...	...	...	...	...	...	

From the tabulated chart $\frac{M}{\theta}=\frac{60}{234}$ gm/deg. for the particular specimen. Hence from the equation calculate the value of n.

Conclusion—Since in the equation, the radius of the wire occurs as a fourth power, it should be very accurately measured, otherwise the percentage of error would be considerable. Each time after increasing or decreasing the loads, the student should wait for a minute or so before taking any reading. Frequent twisting of the wire generates heat and alters the value of rigidity although to a small extent. If the instrument is provided with levelling screws at the base, the disc should be levelled, in order to make the experimental wire vertical.

Oral Questions

What is torsional rigidity? What is the difference between longitudinal stress and shearing stress? Explain the nature of stress applied in your apparatus and the corresponding strain. Is there any elastic limit for the particular type of elasticity? What is the state of the specimen if the elastic limit is exceeded? How will the twist change, if you use a longer wire of the same material or if the wire be thicker.

Simple Pendulum

An ideal simple pendulum consists of a mass suspended from a frictionless support with a *weightless, inextensible* and *perfectly flexible string*. Since these ideal conditions cannot be attained, a simple pendulum in practice consists of a mass suspended from a hook by a thin inelastic thread. Fig. 65 represents an arrangement of a simple pendulum. B is a metal bob suspended from a support by a thin string preferably of unspun silk. When the bob is displaced slightly from its position of equilibrium and then released, it oscillates to-and-fro with simple harmonic motion. The period of a complete oscillation is given by the formula (*Vide* Basu & Chatterjee's Intermediate Physics, Chap. VIII. Vol. I)

$$T=2\pi\sqrt{\frac{l}{g}}$$

where T = Period of a complete oscillation, *i.e.*, the time required to execute a complete to-and-fro movement.

l = Length of the Simple Pendulum *i.e.*, the length from the point of support to the centre of gravity of the bob.

g = Acceleration due to gravity at the place of experiment.

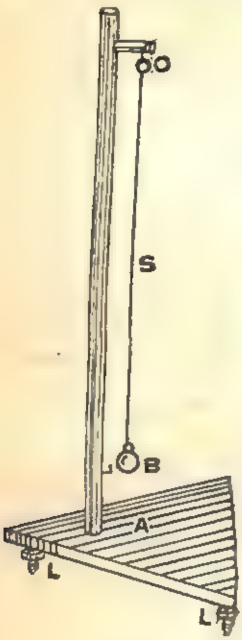


Fig. 65

This formula holds good so long as the pendulum oscillates through a small arc.*

Laws of Simple Pendulum—The equation for the period T of a simple pendulum depends upon its length l and acceleration due to gravity g. Hence we derive the following laws :—

Law of Isochronism—The period of complete oscillation of a simple pendulum of a *given length* at a place of experiment is the same provided the amplitudes of oscillations are small ; in short, the oscillations of a simple pendulum are isochronous.

Law of Length—The period of oscillation of a simple pendulum varies directly as the *square root of its length* at a place of experiment ; that is $T \propto \sqrt{l}$ if g is constant.

Law of Gravity—The period of oscillation of a simple pendulum of a given length varies inversely as the square root of the acceleration due to gravity ; that is $T \propto \sqrt{1/g}$ if l is constant.

Law of Mass—The period of oscillation of a simple pendulum of a given length is independent of the mass or material of the bob, provided that the experiment is carried out at the same locality.

Date—

Experiment 24

To Verify the Law of Isochronism and the Law of Mass of a Simple Pendulum

Theory—The period of oscillation of simple pendulum of a given length is the same for any amplitude provided the extent of swing is small and the period is independent of the mass or material of the bob.

---

* The arc should be so small that the sine of the angle subtended by half the arc at the centre of the circle may be put equal to the circular measure of that angle to the required degree of approximation. For a semi-arc of 4°, sin 4° = ·06976 and 4° = ·06981, the percentage difference being ·07%. For a semi-arc of 8°, sin 8° = ·13917 and 8° = ·13963, the percentage difference being ·3%. So for a simple pendulum experiment, considering the percentage of accuracy attained due to other factors, a semi-arc upto 8° may be allowable.

Apparatus—A vertical stand with a hook, a string, a metre scale, a few round bobs of different materials.

[A diagram of a simple pendulum with a stand is to be drawn.]

Procedure—To verify the law of isochronism, set up a simple pendulum by tying one end of the string to the hook of the stand and another end to the hook of the bob, such that the bob is suspended freely (Fig. 66). Now take the bob to one side through a short distance (not more than one-seventh the length of the string)[1] and then release it. It is found to oscillate. In course of oscillations, when the bob comes to one end and is about to retrace its path, start the stop watch[2]. Next when the bob comes to the same position, it executes one complete oscillation and count it as one. In this way go on counting, until the bob completes 20 or 30 oscillations. At the end of the count, stop the watch and note the total interval. Make three of four counts for different amplitudes of swing and tabulate the results. Calculate from each set, the period for a complete oscillation and show that period is sensibly the same for different amplitudes.

To verify the law of mass, tie a bob with a string and suspend it from the support. Measure the length of the string from the point of suspension to the upper surface of the bob with a beam-compass[3]. Next measure the diameter of the bob at a few places with a simple callipers correct to half a millimeter and find the mean radius. The length of the string plus the radius of the bob gives the length of the simple pendulum. Oscillate the pendulum though a small arc and find the time for a given number of oscillations with a stop-watch. Hence get the mean period of oscillation. Take a number of readings for the periods of oscillation with bobs of different masses and materials without altering the effective length of the pendulum.

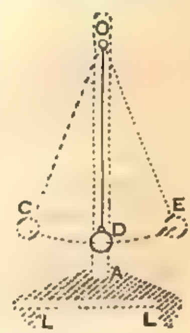


Fig. 66

Results—

(*a*) For the law of isochronism :—

Length of the string : (i) 71·6 cm. (ii) 71·5 cm. (iii) 71·5 cm.

∴ Mean length of the string = 71·5 cm.

Slide callipers used : Diameter of the bob : (i) 1·1 cm. (ii) 1·0 cm. (iii) 1·0 cm. ∴ Mean diameter of the bob = 1·0 cm. or mean radius = 0·5 cm.

---

1. For a still larger oscillation the time period appreciably depends upon the amplitude.
2. Time period does not depend on the position of the bob whence time is counted.
3. A more accurate measurement of length is done by a cathetometer.

Length of the string + radius of the bob = 72 cm.

No. of Readings	Initial Amplitude cm.	Time for 30 oscillations			Mean sec.	Period sec.
		1st set	2nd set	3rd set		
1	2	51·2	51·0	51·0	51	1·70
2	3	51·0	51·2	51·2	51·1	1·70
3	4	50·9	51·0	51·0	51	1·70
4	5	51·2	51·2	51·2	51·2	1·70

(*b*) For the law of mass.

No. of Readings	Material of bob	Radius of bob	Length of string & hook	Equivalent Length	No. of oscillations	Total Time	Period
		cm.	cm.	cm.		sec.	sec.
1	Iron	2·5	87·5	90·0	30	57·0	1·9
2	Iron	1·8	88·2	90·0	30	57·2	1·9
3	Brass	2·7	87·3	90·0	30	57·2	1·9
4	Copper	2·5	88·5	90·0	30	56·8	1·9

Discussions—In the experiment for the verification of the law of isochronism, only one particular length of the pendulum equal to 72 cm. has been taken. The period has been found to be 1·7 sec. for various amplitudes for small ranges of oscillations. If the length is altered, the period is also altered. For the measurement of time period for any length of the pendulum, the time for a large number of oscillations should be taken, as this entails a small error in determining the period.*

In the second set of results bobs of different sizes and materials have been used, but the equivalent length of the pendulum has been kept constant. It is found that the period is equal in all cases. Both the experiments are subject to a small error due to the resistance offered by air on the swinging pendulum as well as due to some friction at the point of support.

* In course of measurement of period, we have to start and stop the watch at some particular instants. Suppose that we make an error of ·2 sec. every time in an attempt to record an interval of time. Now if we measure time for a single oscillation, which as we find from the experiment, is 1·70 sec and if the error is ·2 sec, the percentage of error is 12%. But if we measure time for 30 oscillations, the mean value of which is 51·1 sec, and thereby make an equal error of ·2 sec, the percentage of error is ·04%. So to have higher accuracy, the time for a larger number of oscillations should be measured.

Date—

EXPERIMENT 25

To Verify the relation $T \propto \sqrt{l}$ for a Simple Pendulum and to Draw $l-T$ curve

Theory—The period of oscillation of a simple pendulum varies directly as the square root of its length at a place of experiment. In other words

$T \propto \sqrt{l}$, when g is constant.

Apparatus—A vertical stand with a hook, pendulum bob, metre scale, slide callipers, stop-watch.

[The diagram of simple pendulum is to be drawn on the blank page and a description of it is to be given here.]

Procedure—Measure the diameter of the pendulum bob with callipers at five or six different places correct to the nearest millimetre and find their mean value. Half this value gives the mean radius of the bob.

Take a piece of silk thread of about one metre in length and fasten one end of it to the hook of the bob and slip the other end of this thread through the upper suspension hook of the stand and tie it to the stand. Measure the length of the string from the point of suspension to the upper surface of the bob thrice with a metre scale or better with a cathetometer and find the mean value. The equivalent length of pendulum is the sum of the mean length of the string and the mean radius of the bob.

Draw a vertical line with chalk on the wall just behind the thread of the pendulum along the line of sight. Give the pendulum small oscillations taking care that it neither spins nor makes any elliptical orbit while oscillating.*

Start the stop-watch at the instant the thread in its swings passes against the chalk-line. Observe normally against the wall either with naked eye or better through a low power telescope. When again the thread passes against the line in the same direction, then count is it as one oscillation. In this way measure the total time for a given number of oscillations, usually 20 to 30, with the stop-watch. Oscillate the pendulum again and measure another time for equal number of oscillations. Take about 10 lengths of the pendulum from 100 cm. to about 20 cm. at approximately even steps of 10 cm. and arrange them in a tabular form.

Draw a graph showing the relation between length of the pendulum and its period. Choose suitable units to cover the full graph paper taking length as abscissa and period as ordinate. The graph, so drawn, is parabolic.

---

* While pulling the bob to one side to make it oscillate, do not drag it through a distance which is more than one-seventh the length of the pendulum.

Results—

Readings for the Diameter of the bob ;

No. of readings	Main Scale	Vernier Scale	Total	Mean
	cm.	cm.	cm.	cm.
1.	2·9	·04	2·94	3·00
2.	3·0	·01	...	
3.	...	·03	3·03	
4.	3·0	...	3·02	

Mean Diameter = 3·0 cm.
∴ Radius of the bob = 1·5 cm.

No. of Readings	Length of string + hook	Radius of Bob	Length of Pendulum	Time for 20 oscillations			Period of oscillation	Ratio of length and (Period)²
				1st set	2nd set	Mean		
	cm.	cm.	cm.	sec.	sec.	sec.	sec.	
1	98·5	1·5	100·0	41·0	41·2	41·1	2·005	24·87
2	88·5	,,	90·0	38·2	38·0	38·1	1·90	24·93
3	78 8	,,	80·0	35·6	37·0	35·8	1·79	24·96
4	70·5	,,	72·0	34 0	34·0	34·0	1·70	24·83
5	58·5	,,	60·0	31·0	31·2	31·1	1·55	24 97
6	52·5	,,	54·0	29·2	29·6	29·4	1·47	24·98
7	44·4	,,	46·0	27·2	27·2	27·2	1·36	24·81
8	38·5	,,	40 0	25·6	25·6	25·5	1·27	24·67
9	32·5	,,	34·0	23·4	23·4	23·4	1·17	24·84
10	26·5	,,	28 0	21·3	21·2	21·3	1·06	24 92
11	18·5	,,	20·0	17·8	17·8	17·8	0·90	24·70

A graph showing the relation between the equivalent length l of the pendulum and the corresponding period of oscillation T has been drawn on the squared paper (Fig. 67). It is to be noted that for zero length of the pendulum the time period is also nil. Hence the l—T graph would also pass through the origin if the origin be chosen at the intersection of zero values of the co-ordinates.

The last column of the table gives the ratio of the length of the pendulum and the square of the period. For a given value of g the ratio l/T^2 is constant as is found from the equation of a simple pendulum. The ratios have been nearly constant within the limits of experimental errors, the average value being 24·86. The graph of l and T^2 which is a straight line is shown in Fig. 68.

Discussions—A measurement of equivalent length of simple pendulum correct to a tenth of a millimetre does not help accuracy

in the result, firstly because the bob is suspended by a string which is more or less elastic. At the ends of the swing where the tension of the string is slightly less, the string contracts by an amount of the order of 0·1 mm. Secondly, because an average variation of length of a simple pendulum by 0·01 cm. causes a variation of the period by about 0·005 sec. and at the end of 20 oscillations, the total variation of the interval is about 0·1 sec. which is half of the smallest unit on the stop-watch. For this reason the length of the pendulum has been taken correct to a millimetre in each case.

The bob should be made to oscillate through a *very small arc* in a vertical plane. If it oscillates in an elliptical path, its time period is increased and hence the equation is not satisfied. To avoid the latter effect there should be no spinning or jerky motion of the bob at start. The small friction of the string at the point of support, the viscous resistance of the air on the oscillating pendulum and the violation of amplitude restriction specially for smaller lengths of the pendulum are the principal sources of errors in the experiment.

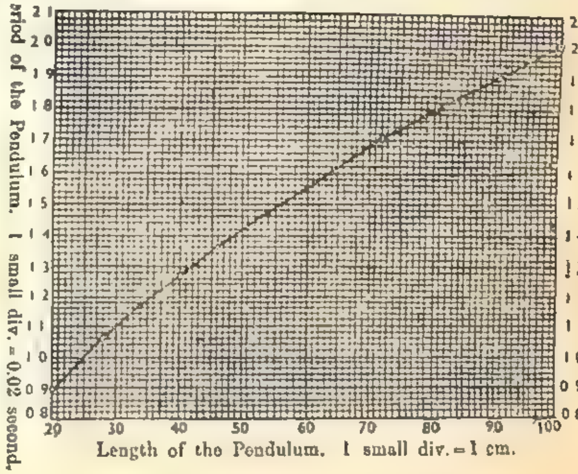


Fig. 67 l—T Graph of a Simple Pendulum

Date—

Experiment 26

To Determine Graphically the Lengths of a Simple Pendulum beating seconds and half-seconds

Theory—A pendulum beating half-seconds in one whose period is one second and a pendulum having a period is of two seconds is called a seconds pendulum. In any case the period is given by the general relation,

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where, T, l and g have their usual significances.

Apparatus—The same as those of Expt. 25.

Procedure—The same as that of Expt. 25.

Results—The same as that of Expt. 25 ; l—T graph should be drawn. Referring to the graph it is found that the length of simple pendulum having a period of 2 sec. is approximately 99·3 cm. Since the smallest division of the abscissa represents a length of 1 cm. any fraction of this unit is to be measured by eye-estimation. Similarly, the length of the pendulum beating half-seconds is 25·0 cm.

Discussions—The acceleration due to gravity at Calcutta is known to be 978 cm/sec^2 and applying this value of g in the equation, the length of the seconds pendulum is found to be 99·3 cm. and that of a half-second pendulum 24·8 cm. The percentage of error in the former case is 0·1% and while in the latter it is 0·8%. This supports the view that the measurement of smaller quantities usually involves a larger amount of error. The principal sources of errors are like those of Expt. 25.

Date—

EXPERIMENT 27

To Determine the value of g at (Calcutta) with a Simple Pendulum

Theory—The period T of a simple pendulum is related to it equivalent length l and acceleration due to gravity g at the place observation by an equation of the form.—

$$T = 2\pi\sqrt{\frac{l}{g}}$$

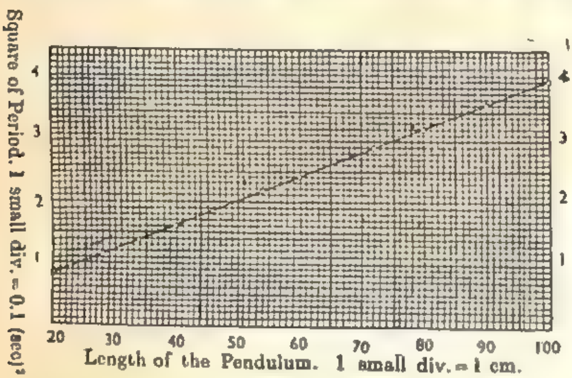


Fig. 68

Apparatus—The same as those of Expt. 25.

Procedure—The same as that of Expt. 25.

Results—A similar tabulation as that of Expt. 25. It is preferable to give the graph of l—T^2 here instead of l—T. Since the graph of l—T^2 is straight line passing through the origin, (Fig. 68). The average value of l/T^2 as calculated in the experiment is 24·86 cm. per sec^2.

Therefore $g = 4\pi^2 \dfrac{l}{T^2} = 4 \times 3{\cdot}14^2 \times 25{\cdot}86 = 980$ cm./sec.^{2}

Discussions—The same as that of Expt. 25.

The average value of l/T^2, as found from calculations is 24·86 cm/sec.^{2}. The largest variation from this mean value is 24·98 on the high side and 24·70 on the low side. The variation is about ·14 cm/sec.^{2} on the average. Hence the percentage of error is

$$\pm\frac{{\cdot}14}{24{\cdot}86} \times 100 = {\cdot}5\% \text{ nearly.}$$

EXERCISES

1. Determine graphically the period of a simple pendulum of a length of 1 metre.
2. Determine the period of a simple pendulum of the length of 5 cm.
3. How it is possible to determine the length of a pendulum for an inaccessible point ?

ORAL QUESTIONS

What is the nature of the motion executed by a simple pendulum? Define the terms, period and amplitude of a simple pendulum? Why should the amplitude of oscillations be small? What is the equivalent length of a simple pendulum? Does the period alter if the apparatus is taken to a different locality, and how? What is a seconds pendulum? A pendulum clock is going slow, how would you correct it? Why should you take a large number of oscillations in determining the period? If the material or the size of the bob is altered, other factors remaining constant, should there be any change in the period? What is the unit of acceleration? If two unequal masses are allowed to fall freely under gravity will they reach the surface of the earth in the same time? If so, why?

Date—

EXPERIMENT 28

To Measure the Acceleration due to Gravity using a Spiral Spring

Theory—If mass m, hanging at the end of a very light spiral spring, be displaced a little vertically downwards and then released, it would continue to move up and down simple harmonically having a period T, where

$$T = 2\pi\sqrt{\frac{\text{load placed}}{\text{restoring force per unit extension}}} = \sqrt{\frac{m}{k}}$$

But $k = Lg$ where L is the load in grams to produce unit extension.

Then $T = 2\pi\sqrt{\frac{m}{Lg}}$

If however the mass of the spring, say M, be taken into consideration, then the periodic time is given by,

$$T = 2\pi\sqrt{\frac{m+M}{Lg}} \text{ whence}$$

$$T^2 = \frac{4\pi^2 m}{Lg} + \frac{4\pi^2 M}{Lg}$$

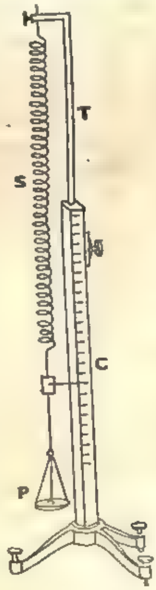


Fig. 69

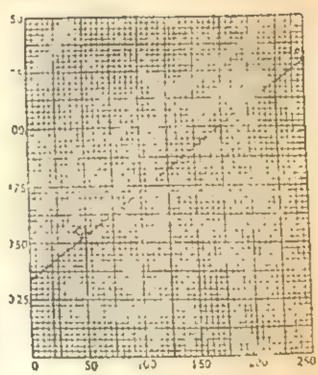


Fig. 70

Apparatus—A spiral spring about a metre in length suspended from a rigid support and carrying a horizontal pointer at the lower end, a light scale pan, a scale vertically fixed behind the spring, a weight box and a stop watch.

Procedure—If the mass of the scale pan is not supplied, take out the scale pan and weight it in a balance to the nearest decigram. Let its mass be w gm. Then suspend the scale pan from the spring and when the pointer is steady, take the reading of the pointer with reference to the scale attached (fig. 69). Assuming the pan to be the

dead load on the spring, this would be the zero reading. Then add some "weights' from the weight box until the spring elongates by about 2 cm. and take the reading of the pointer. Increase the load on the pan by equal amounts four or five times and take the reading of the pointer for each increment of load. The maximum load should in no case exceed the limit indicated on the apparatus. Tabulate the observations as shown in results and get the value of the load in grams to produce unit extension.

Next put a little load w_1 on the scale pan from the weight box. Then the total load on the spring is $w_1 + w = m$ gms. Now displace the scale pan vertically down through a distance of about 2 cm. and then release it. It is found to oscillate up and down with simple harmonic motion. Measure the time for 10 swings in exactly a similar way that is followed in a simple pendulum experiment. Change the load by some known amount three or four times and find the time for 10 swings each time. Tabulate the observations as shown in Results and draw another graph showing the variations of m with corresponding T^2, where T represents the time period for a single oscillation corresponding to a load m on the spring (fig 70).

Results—

The maximum admissible load including the scale pan, as was indicated on the instrument = 350 gm.

Mass of the scale pan and the pointer = 62 gm.

Maximum load used in the scale pan = 200 gm.

No. of Readings	Load in scale pan gm.	Pointer Reading cm.	Extension cm.	Load per unit extension gm.	Mean load per unit gm./cm.
1.	0	70·20	0		
2.	50	74·85	4·65	10·7	
3.	100	79·50	9·30	10·65	10·7
4.	150	84 20	14·60	10·84	
5.	200	88·90	18·70	10·65	

$\therefore$ Load per unit extension = L = 10·7 gm. per cm.

No. of Readings	Load with scale pan gm.	Time for 10 swing			Period sec.	Period² sec²
		sec.	sec.	Mean. sec.		
1.	100	8·4	8·5	8·45	·845	73
2.	150	9 6	9·6	9·6	·960	92
3.	200	10·5	10·4	10·45	1·04	1·08
4.	250	11·3	11·3	11·3	1·13	1·28

From the graph $OC = \dfrac{4\pi^2 M}{Lg}$

If CB is drawn parallel to the load axis, then $\tan \angle BCA = \dfrac{4\pi^2}{Lg}$

Now tan $\angle BCA$ from graph $= \frac{AB}{BC} = \frac{1{\cdot}28 - {\cdot}50}{208} = \frac{{\cdot}78}{208}$

$$\therefore \quad g = \frac{4\pi^2}{LT^2}m = \frac{4 \times 3{\cdot}14^2 \times 208}{10{\cdot}7 \times {\cdot}78} = 982 \text{ cm/sec.}^2$$

Discussions—The successive loading of the spiral spring should be such that the extension is proportional to the load, otherwise a permanent distortion of the spring would be brought about by too much loading and the expression for the time period as given in thoery would not be satisfied.

The pan attached to the spring should be light and small. A pan of large diameter would damp the oscillations too much and a large number of oscillations may not be obtained. The extension of the spring by a scale and pointer may be read correct to half a millimetre and so this method of measuring g has an accuracy not greater than that of a simple pendulum experiment.

Drawing of Capillary Tubes

A glass tube of medium bore and of length of about a metre is taken. It is washed througly with dilute hydrochloric acid and then with caustic soda solution. Finally, tap water is run through the pipe to remove all traces of impurities. The glass tube is then dried by passing a current of hot air from a blower.

The glass tube is then cut into four or five equal parts by a file. A fish tail burner is lighted and any one glass tube, being held by fingers, is taken over the flame so that its middle part is heated. While the tube is heated, it is slowly rotated about its length so as to ensure uniform heating at its middle region.

When the middle part becomes soft, the tube is taken outside the flame, held vertically and pulled steadily lengthwise. It is found to be constricted at its middle part. After the the tube is cooled, the capillary part of the tube it cut by a file. In this way a number of capillary tubes are drawn. The best capillaries for work on surface tension are those having circular cross-secton and having a bore between ·5 to 1·5 mm in diameter.

EXPERIMENT 29

Date—

To Measure the Surface Tension of Water by Capillary Tube Method.

Theory—If water rises to a height of h cm. within a vertical capillary tube of internal radius r cm, then the surface tension T of water at that temperature is given by,

$$T = \tfrac{1}{2}r\rho g\left(h + \frac{r}{3}\right) \text{dynes per cm.}$$

where ρ = density of water at that temperature and g = acceleration due to gravity.

Apparatus—A few drawn glass capillary tubes, a thin glass plate of width about 1 inch, a glass trough, a vernier microscope, a steel pointer and a small quantity of paraffin wax.

Procedure—Draw five or six pieces of capillary tubes, having a probable diameter variation from ·5 to 1·5 mm. From the uniform part of the capillaries so drawn, choose about 10 cm length of each tube and break its ends by pressure of finger tips or by a fine file.

Take a thin glass plate P about 10 cm. long and 2 cm. in width (fig. 72). Now place the capillary tubes tranversely on the glass plate about 1 cm. apart from each other, so that the ends of the capillaries are fairly in a line projecting above and below the plate (Fig. 72). The tube must be placed parallel to each other. Get a straight steel pointer about 10 cm. long and place the pointer parallel to the tubes so that one end of the pointer is a bit above upper ends of the tubes. Then fix the pointer and the tubes to the glass plate by dropping molten paraffin wax.

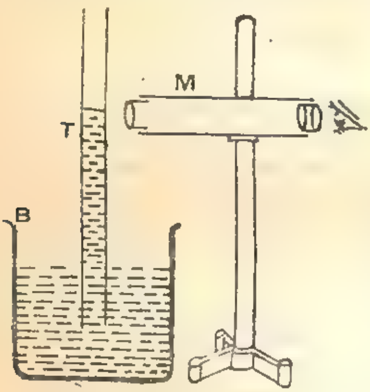


Fig. 71

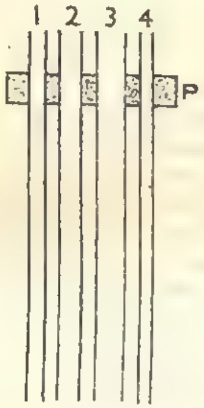


Fig. 72

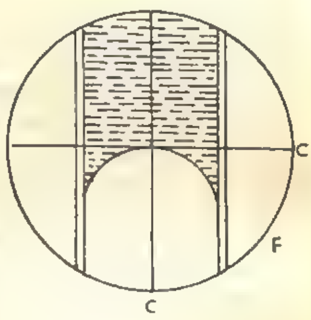


Fig. 73

Now fix the plate over a trough filled with water in such a way that the pointer and the tubes are held vertically and the end of the pointer *just touches* the surface of water, when ends of the capillaries would already lie within water. Check the verticality of the pointer with a plumb line. Water is found to rise to different heights within the tubes (Fig. 71).

Find the least count of the vernier attached to the microscope. Make the axis of the microscope horizontal and focus its crosswires with the eye piece. Now focus the pointer and raise the microscope tube with the rack and pinion arrangement until the image of the tip of the pointer touches the horizontal cross-wire (fig. 73) Take the reading of the vernier attached to the vertical scale. Two or three readings for this position are to be taken for separate adjustment correct to 2 places of decimals in cms. Take similar readings for the levels of water within the capillary tubes. The meniscus of water level within each tube is concave but it appears convex through the microscope and the crosswire is to be made tangential to the surface before taking a reading (Fig. 73). For each surface three readings should be taken each time either raising or lowering the microscope.

Then break each capillary tube at the region of water level with a fine file and place the tubes in a horizontal position with broken ends pointing towards the microscope objective. Then focus microscope against a tube when its round section is seen in the field of view. Measure the horizontal diameter of each bore with the horizontal scale and the vertical diameter with the vertical scale of the microscope stand. Take three readings for each diameter. Lastly measure the length of the pointer with the microscope and note the temperature of water.

Reults—

......vernier divisions = ...main scale divisions

main scale division = ... cm.

∴ least count of the vernier = ...cm.

	Main Scale cm.	Vernier scale cm.	Total cm.	Mean cm.	Base reading of pointer cm.	Height of water columns cm.
Top of Pointer	{	... ...	... ...	...		...
Tube 1	{	... ...	... ...	...	...	...
Tube 2	{	... ...	... ...	...		...
Tube 3	{	... ...	... ...	...		...

Diameter of Tubes—

	Horizontal			Vertical			Mean cm.
	M.S.	V.S.	Total cm.	M.S.	V.S.	Total cm.	
Tube 1	{	... ...	... ...	... ...	... ...	... ...	...
Tube 2	{	... ...	... ...	... ...	... ...	... ...	...
Tube 3	{	... ...	... ...	... ...	... ...	... ...	...

Hence T = ...at room temperature.

Discussions—The water used in the experiment should not be distilled water, since during distillation process vapour of water comes in contact with various tube joints having wax sealing and is thereby contaminated. Tap water should be used. Capillary

tubes selected should be of round cross-section and must be placed vertically.

When the capillary tubes are fixed on the water surface, water may not rise up within the tubes to the required heights due to stickiness of air bubbles. For this reason slight tapping of the tubes may be necessary. It is experimentally found that tubes having diameters of ·5 to 1 mm. give best result.

ORAL QUESTIONS

What is surface tension? Why do you use capillary tubes in measuring surface tension? What is the effect on your measurement if the tubes become greasy? Why do you fix up the capillary tubes vertical? Why should the tubes be of circular section? Can you give a few common illustration of the effect of surface tension? What is the effect of temperature on surface tension? A drop of water and little quantity of mercury are placed on a horizontal glass plate. Explain their nature of shape.

Moment of Inertia—The idea of the moment of inertia is derived out of rotational motion of a body about a given axis. Let the body be imagined to be composed of n number of particles of masses $m_1, m_2, m_3 \ldots m_n$ (n being taken to be very large) and let the distances of the particles from the axis of rotation be $r_1, r_2, r_3, \ldots r_n$. The the moment of inertia I_a about the given axis of rotation is given by the *summation* of each particle multiplied by the square of its corresponding distance from the given axis. That is,

Moment of Inertia about the given axis

$$= I_a = m_1 r_1^2 + m_2 r_2^2 + m_3 r_3^2 + \cdots\cdots + m_n r_n^2 = \Sigma m r^2$$

(For a detailed study vide Basu and Chatterjee's Intermediate Physics, General Physics. Art. 43 and Appendix).

If ω be the angular velocity of a body, its angular momentum about the given axis is $I \times \omega$ where I_a is the moment of inertia about the given axis. If the angular velocity changes with time, such a change is due to the effect of a couple or a torque acting on the body. The torque F is given by,

$$F = I_a \frac{d\omega}{dt}$$

where $d\omega/dt$ denotes the rate of change of angular velocity with time. If however the body rotates with a constant angular velocity ω, the kinetic energy of the body is given by,

$$K.E = \tfrac{1}{2} I_a \omega^2.$$

It is to be remembered carefully that the value of the moment of inertia depends upon the distribution of mass around the axis of rotation. If for the same body, the axis of rotation is changed, the distribution of mass around is new axis of rotation changes, and so the value of the moment of inertia would thereby be altered. The unit of the moment of inertia in the C.G.S. system is gm. × cm.^{2} and in the F.P.S. system it is lb. × ft.^{2}.

Radius of Gyration—The point of gyration of a body with respect to a certain axis is defined to be an imaginary point with respect to that axis, at which the whole mass of the body is supposed to be concentrated. In the expression for the moment of inertia, if we put $\Sigma mr^2 = Mk^2$ where M denotes the mass of the body, then k is called its radius of gyration with respect to the given axis. If the axis of rotation changes, the radius of gyration would take a different value, even if the body remains the same.

Moments of Inertia of Symmetrical bodies—The moment of inertia of symmetrical bodies can be found theoretically from a knowledge of their volume, shape and density. The following are the values of moments of inertia of a few symmetrical bodies.

1. Uniform rod of mass M and of length l about an axis perpendicular to its length and passing through its centre of gravity (Fig. 74) $= \frac{Ml^2}{12}$.

2. Uniform rod of mass M and of length l about an axis perpendicular to its length and passing through its end (Fig. 75) $= \frac{Ml^2}{3}$.

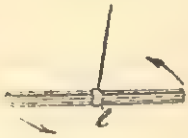


Fig. 74

Fig. 75

3. Rectangular thin plate of mass M and of sides a and b about an axis passing through its centre and parallel to the side of length b (Fig. 76) $= \frac{Ma^2}{12}$; also parallel to the side a (Fig. 77) $= \frac{Mb^2}{12}$.

Fig. 76

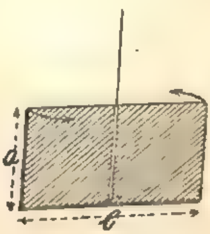


Fig. 77

4. Rectangular plate of mass M and of sides a and b about an axis passing through its centre and perpendicular to the face (Fig. 73) $= M\frac{a^2+b^2}{12}$.

5. Circular disc of mass M and radius r about any diameter (Fig. 81) $= \frac{Mr^2}{4}$.

6. Circular annulus of radii r_1 and r_2 and of mass M about a diameter $= \frac{M}{4}(r_1^2 + r_2^2)$.

7. Circular disc of mass M and radius r about an axis passing through its centre and perpendicular to the face (Fig. 79) $= \frac{Mr^2}{2}$

8. Circular annulus of radii r_1 and r_2 and of mass M about an axis passing through its centre and perpendicular to the face $=\frac{M}{2}(r_1^2+r_2^2)$.

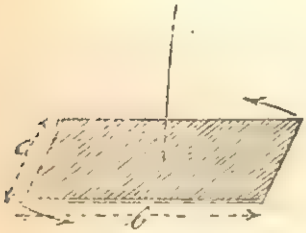


Fig. 78

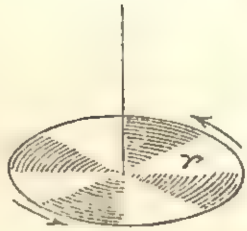


Fig. 79

Fig. 80

9. Circular disc about a tangent $=\frac{5}{4}\,Mr^2$.

10. Right circular solid cylinder of mass M and radius r about its axis (Fig. 80) $=\frac{Mr^2}{2}$.

11. Circular annulus about a tangent $=\frac{M}{4}(5r_2^2+r_1^2)$.

12. Thin spherical shell about the centre $=Mr^2$.

13. Thin spherical shell about the diameter $=\frac{2}{3}\,Mr^2$.

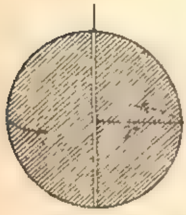


Fig. 81

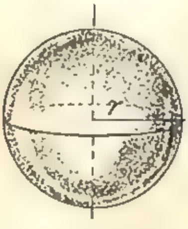


Fig. 82

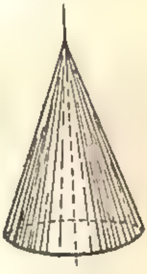


Fig. 83

14. Thin spherical shell about a tangent $=\frac{5}{3}Mr^2$.

15. Solid sphere about the centre $=\frac{2}{5}Mr^2$.

16. Solid sphere about a diameter (Fig. 82) $=\frac{2}{5}Mr^2$.

17. Solid sphere about a tangent $=\frac{7}{5}Mr^2$.

18. A solid cone of base radius r and of mass M about its axis (Fig. 83) $=\frac{3}{10}Mr^2$.

Date—

EXPERIMENT 30

To find the Moment of Inertia of a Body about any Axis.

Theory—The moment of inertia of a body about any axis is the sum of the product of elementary masses composing the body and

the square of their respective distances from the axis. If I be the moment of inertia, then $I = \Sigma mr^2$.

Let I_0 be the moment of inertia of a horizontal circular disc with components about a vertical axis of suspension, c the torsional couple of the suspension wire for a twist of one radian and T_0 the time period of rotational oscillation of the disc with components, then for small oscillations,

$$T_0 = 2\pi\sqrt{\frac{I_0}{c}} \quad \text{or,} \quad I_0 = \frac{T_0^2}{4\pi^2} \times c \qquad \dots \qquad (1)$$

Let I_1 be the known moment of inertia of a body about an axis through its centre of gravity. If this body be mounted on the disc with its centre of gravity coinciding with the axis of suspension and if T_1 be the time period of the combination, then

$$T_1 = 2\pi\sqrt{\frac{I_0 + I_1}{c}} \quad \text{or,} \quad I_0 + I_1 = \frac{T_1^2}{4\pi^2} \times c \qquad \dots \qquad (2)$$

From eqn. (1) and eqn. (2),

$$\frac{I_0 + I_1}{I_0} = \frac{T_1^2}{T_0^2} \quad \text{whence} \quad I_0 = \frac{T_0^2}{T_1^2 - T_0^2} I_1 \qquad \dots \qquad (3)$$

This gives the value of I_0 the moment of inertia of the disc and components. Now let I be the moment of inertia of another body about the given axis. If this body be placed on the disc with its axis coinciding with the axis of suspension (the known body being removed) and if T_2 be the time period of rotational oscillations, then

$$T_2 = 2\pi\sqrt{\frac{I_0 + I}{c}} \quad \text{or,} \quad I_0 + I = \frac{T_2^2}{4\pi} \times c \qquad \dots \qquad (4)$$

Combining eqn. (4) with eqn. (1), and then with eqn. (3) we get,

$$I = \frac{T_2^2 - T_0^2}{4\pi^2} \times c = \frac{T_2^2 - T_0^2}{T_0^2} I_0 = \frac{T_2^2 - T_0^2}{T_1^2 - T_0^2} I_1 \qquad \dots \qquad (5)$$

Thus the value of I is obtained in terms of I_1

Apparatus—The apparatus consists of uniform circular metal disc D having a concentric groove G cut on its surface (Fig. 84).

Three or four bent pieces R of iron or lead rods of equal length and fitting into the groove are provided (fig. 84*a*). Two thin identical metal rods are fixed vertically being equidistant from the centre of the disc and normal to the surface. A uniform horizontal rod forms the cross-piece of the rods. One end of a fairly stout wire is soldered to the mid-point of the cross-piece and its other end is fastened to a rigid support B. A mirror M is sometimes attached to the lower end of the wire. Two spirit levels are fixed on the disc with their axes at right angles to each other and at such distances as not to disturb the centre of gravity of the suspended disc. A very light pointer is sometimes provided with the disc (not shown in the diagram).

Another type of moment of inertia apparatus is shown in Fig. 85. It differs from the previous apparatus only in its method of suspension. Three thin rods, fixed with the disc, come to a point whence the suspension wire starts.

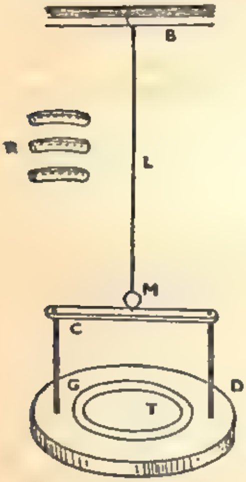


Fig. 84

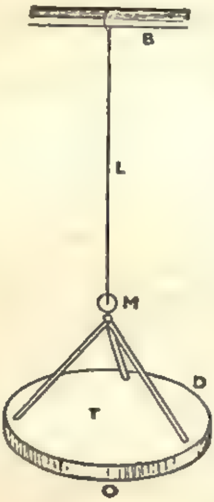


Fig. 85

Procedure—Slide the bent pieces through the groove and adjust their positions so that the spirit levels indicate that the disc is horizontal. If the apparatus is provided with a pointer, fix a plumb line or a vertical stand against the pointer. If, on the other hand, a mirror is attached, make a light and scale arrangement.

Turn the table through a *small* angle and release it, so that it makes rotational oscillations. If any linear oscillation is noticed, *softly* hold the suspension wire to stop such linear swings. Now as the pointer moves past vertical mark in a certain direction, start the clock and measure time for 30 oscillations. Take three such observations and hence find the mean period of a single oscillation. Let the value be T_0 sec. If on the other hand, there is the light and scale arrangement, the spot of light oscillates on the scale. In a similar manner, count time for 30 oscillations.

Take a right circular cylinder and weight it in a balance. Measure its diameter with a slide callipers at 2 or 3 different places and at every place measure two rectangular diameters. From such data, calculate the moment of inertia of the cylinder. Let it be I. Now place the cylinder centrally over the disc in such a way that the spirit levels indicate correct levelling. The cylinder has been placed co-axially. Then turn the table through a *small* angle and release it. Measure the time period of oscillations according to the directions given in the preceding paragraph. This gives T_1 sec. Hence from eqn. (3), calculate the moment of inertia of the disc and components, which is I_0.

Take out the cylinder and place the body under examination on the disc with its centre coinciding with the *given axis* of the body. If the given axis does not coincide with the centre of gravity of the body, the bent pieces would have to be slided through the groove to obtain balance of the disc with the body; the balance is to be checked with the spirit levels. When the balance is obtained, measure the time period of oscillations by a method as given previously. Let this time period be T_2.

Results—(A typical set a data is given here)

Mass of the given cylinder (iron) = (i) 376.70 gm. (ii) 376.71 gm. (iii) 375.68 gm.

∴ Mean mass = 376.70 gm.

Diameter of the cylinder = (i) 4.01 cm. (ii) 4.01 cm. (iii) 4.00 cm.
4.00 cm. 3.99 cm. 4.02 cm.

(For Tabulation with vernier callipers, vide pp. 30)

The mean radius of the cylinder = 2 cm.

∴ Moment of Inertia of the Cylinder about its axis I_c

$$= \frac{376.7 \times 4}{2} = 753.4 \text{ gm. cm.}^2.$$

Time Period observations.

Load on Disc and components	Time for 30 oscillations (i) Sec.	(ii) Sec.	(iii) Sec.	Mean time for 30 oscillations Sec.	Time Period Sec.
Nil	93.6	93.5	93.6	93.6	$3.12 = T_0$
Cylinder	120.7	120.6	120.6	120.6	$4.02 = T_1$
A rectangular rod	109.2	109.1	109.1	109.2	$3.64 = T_2$

The moment of inertia of the disc and components

$$I = \frac{3.12^2}{4.02^2 - 3.12^2} \times 753.4 = 1141.3 \text{ gm. cm.}^2.$$

The moment of inertia of the body about the given axis

$$I = \frac{3.64^2 - 3.12^2}{3.12^2} \times 1141.3 = 412.2 \text{ gm. cm.}^2.$$

Discussions—Care must be taken to see that during torsional oscillations, there is no linear swing of the apparatus. The angular oscillations should be small, as otherwise the expression for the time period will not hold. The angular oscillations should not be too small, since in such a case it becomes difficult to count the oscillations and the time for a given number of swings.

The suspension wire can bear a safe limit of weight. The load placed must be less than this limit. The moment of inertia of the disc with components should be equal or less than the moment of inertia to be found for a more accurate experiment. Hence T_0 should have a small value.

ORAL QUESTIONS

Define moment of inertia. What is the radius of of gyration? What for are the pieces of bent rods within the groove of the apparatus? What is the use of the spirit level? If the disc is not balanced horizontally, would be moment of inertia change? Why? Distinguish between rotational and linear oscillations. Will a displacement of bent rods around the groove alter the time period of rotational oscillations?

CHAPTER III

EXPERIMENTS ON HYDROSTATICS AND PNEUMATICS

Archimedes' Principle

Almost all experiments on Hydrostatics work directly or indirectly upon Archimedes' principle which states that—

When a body is immersed either wholly or partly in a fluid at rest, it appears lose a part of its weight which is equal to the weight of the fluid displaced.

To verify the truth of this principle a body such as a piece of stone is ordinarily weighed in air and then in any other medium, such as water. The mass of the body in water is found to be always less than its mass in air. The difference of these two masses would be equal to the mass of water having a volume equal to that of the body. In order to weigh a body in water a *hydrostatic balance* is commonly used.

Hydrostatic Balance

It is an ordinary physical balance with some modification (Fig. 86). A small table T is placed on the base board over the left pan so as not to touch it. The height of the table is such that when the beam is raised, the pan can freely swing beneath it.

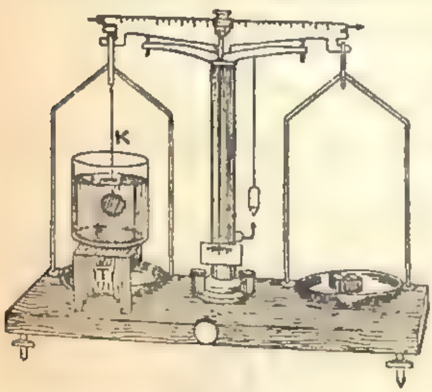


Fig. 86

To find the mass of a body in air with this balance, one end of a piece of fine thread or horse hair of a suitable length is fastened to the left stirrup and its other end is left free in air. The nut screws are then adjusted so that the pointer oscillates equally with empty pans. Then the body B, which is to be weighed, is tied to the free end of the thread so as to be suspended in air as shown in the figure. Then suitable weights are placed on the right pan till, on making the balance free, equal oscillations of the pointer are obtained on the scale. The mass of the weights is then equal to the mass of the body in air.

To find the mass of the body in water, the rider table is placed over the base board so as not to touch the left pan. A glass beaker is then placed over the table so that the body B hangs within it without touching the walls. Water is then slowly poured into the beaker until the body is completely immersed. Suitable weights are now placed on the right pan to counterpoise the body; the equilibrium is obtained when the pointer symmetrically oscillates or comes to rest at the middle the scale.

Date—

EXPERIMENT 31

To Verify Archimedes' Principle for completely immersed Bodies

Theory—When a body is immersed in a liquid it appears to lose a part of its weight which is equal to the weight of the displaced liquid.

Apparatus—A hydrostatic balance, a displacement jar, a glass beaker and heavy insoluble body such as piece of metal.

Procedure—Raise the beam of the balance by turning the key and observe the oscillations of the pointer. If unequal oscillations are found, adjust the balance according to direction as given on p. 61.

Take two pieces of string or horse hair of equal length. Tie the metallic body with one piece of string and suspend it from the hook of the left scale pan, so that it hangs in air. Put the other string on the right pan. Place suitable weights by repeated trials on the right pan to counterpoise it. This gives the weight of the metal piece in air. Take two such readings of the weight and find the mean value. Lower the beam on the stirrups.

Next place the rider table so as not to touch the left scale pan (vide Hydrostatic Balance). Put a glass beaker on the rider table, such that the metal piece is within the beaker but not touching its sides. Slowly pour water within the beaker to such a level that the body is completely immersed.

Measure the weight of the body in the completely immersed position. Take two such weights and find the mean value. The difference of the mean weights of the body in air and in water, according to Archimedes' principle, gives the mass of water displaced.

Throw away water from the glass beaker. Dry it as completely as possible and then weigh it in the balance. Fill the displacement jar completely with water and when water stops trickling down the spout, place the glass beaker under the stem of the jar. Tie the metallic body with a piece of string and slowly lower it into the jar so as to be completely immersed. Carefully collect all the water running into the beaker. Then weigh the beaker with water in the balance. The difference of these two weights gives the amount of water displaced. Collect the water from the displacement jar three times and take the weight of water displaced each time. Take the mean of such observations. It is found that the difference of the mean weight of the body in air and that in water is equal to the mean weight of water collected.

Results—

No. of readings	Mass of solid in air	Mass of solid in water	Difference	Mean	Mass of beaker	Mass of water collected	Mean
	gm.	gm.	gm.	gm.	gm.	gm.	gm.
1.	18·23	...	...	...		2·19	
2.	...	16·03	...	2·20		...	2·20
3.	...	...	2·19			...	

Discussions—The experiment cannot be done with a liquid in which the material of the sinker is soluble. If an attempt be made to weigh a piece of alum in water, alum will continuously go into solution and a correct weight will not be obtained. In this case the solid will have to be weighed in a liquid in which it is insoluble. Porous bodies cannot be correctly weighed in any liquid due to presence of air bubbles within it unless special precautions are taken. It is often difficult to get oscillations of the pointer while the body is within the liquid. In this case the resting point of the pointer is to be observed.

Exercises

1. Determine the volume of a given solid by Archimedes' principle.
2. Determine the density in gm. per c.c. of the given solid by applying Archimedes' principle.

Date—

Experiment 32

To Verify Archimedes' Principle for partially immersed Bodies

Theory—When a body floats on a liquid, the weight of the body is equal to the weight of liquid displaced by the body.

Apparatus—A physical balance, a displacement jar, a glass beaker and a piece of solid (say wood) which floats on water.

[A description of a physical balance and that of a displacement jar are necessary here.]

Procedure—Take three sets of readings for the mass of the piece of wood and find the mean mass. Dry the beaker and weigh it three times in the balance. Find the mean weight of the glass beaker.

Fill the jar completely with water and wait till water stops trickling down the spout. Now place the beaker under the spout and slowly place the piece of wood on water within the jar. Some water is found to be collected into the beaker and wait until the last drop of water falls into the beaker.

Weigh the beaker with water in it. Repeat this water collection procedure three times, weighing the beaker each time. Take the mean of these weights. The difference of the two mean weights gives the weight of water collected. Now tabulate the readings as below :—

Results—

No. of Readings	Mass of solid in air	Mean	Mass of Beaker	Mean	Mass of Beaker & water	Mean	Mass of water collected
	gm.	gm.	gm.	gm.	gm.	gm.	gm.
1.	...	...	...	...	...	...	...
2.	...	...	...	...	...	...	...
3.	...	...	...	...	...	...	...
			...	...	...	...	...

Discussions—Care must be taken to place the body on water very slowly so that the water surface is not disturbed much, as otherwise some more water would trickle down from the jar making

the result inaccurate. Accumulation of air bubbles on the body or inside it would vitiate the result too much. In taking the weight of beaker and water contained in it, the beaker should be dried every time a fresh reading is taken.

Date— EXPERIMENT 33

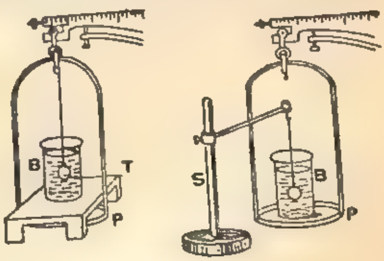
To Verify the Law of Reaction with a Hydrostatic Balance.

Theory—According to Newton's Third law of Motion, action and reaction are equal and opposite. When body is suspended in a fluid, its apparent weight is equal to the difference of its real weight and the weight of the fluid displaced. The body thus presses the fluid downwards. This is the acting force. By law of reaction, the body is also pressed upwards by the fluid, the reacting force being equal to the acting force.

Apparatus—A hydrostatic balance, weight box, wooden bridge, small light glass beaker, round marble with suspension hook, some thread, a given liquid, a vertical adjustable stand.

Procedure—Suspend the ball by a suitable length of thread, from the suspension hook of the left pan of the balance so that it hangs in air a little above the pan. Weigh the ball as usual in air correct to the nearest centigramme. Take two separate weights and find their mean, say W_1 which gives the mass of the ball in air Lower down the beam.

Now place the bridge over the left pan so as not to touch it and place the beaker on the bridge so that the ball is well within the beaker, care being taken that the ball does not touch any side of the beaker or its bottom. Carefully pour the liquid into the beaker until the ball is completely immersed (Fig. 87 *a*). Measure the mass of the ball in liquid to the nearest centigramme. Make two measurements and obtain the mean value W_2. This gives the mass of the ball in water. The difference of W_1 and W_2 gives the upward force (thrust) on the ball in the liquid. Lower down the beam and remove the bridge.



(*a*) Fig. 87 (*b*)

Carefully take out the ball from the liquid so that no liquid is spilt out from the beaker. Untie the thread and remove the ball Now place the beaker with the liquid on the left pan and find its mass (Fig. 87 *b*) Take two readings and find the mean W_3. Lower down the beam.

Finally suspend the ball from the stand and gradually lower it into the liquid so as not to touch any side or the bottom of the beaker. Measure the mass of the combination. Take two readings and find the mean W_4. It would be found that W_4 is greater than W_3 and that $W_4 - W_3 = W_1 - W_2$, which verifies the law.

Results—By way of illustration,

Mass of tha ball in air = (i) 10·46. gm. (ii) 10·46 gm.

$\therefore$ Mean mass = 10·46 gm.

Mass of the ball in kerosene = (i) 7·12 gm. (ii) 7·13 gm.;

Mean = 7·12 gm.

$\therefore$ Upward thrust on the ball = 10·36 − 7·02 = 3·34 gm.

Mass of the beaker and kerosene = (i) 47·42 gm. (ii) 47·43 gm.

Mean = 47·42 gm.

Mass of beaker, kerosene and suspended ball = (i) 50·77 gm.

(ii) 50·76 gm.

Mean = 50·76 gm.

Downward thrust due to immersed ball = 50·76 − 47·42 = 3·34 gm.

Discussions—Same as preceding experiment.

Density and Specific Gravity

If equal volumes of different substances are weighed in a balance, they are found to have different masses. The mass per unit volume of a substance is called its **density.** Hence substances have got different densities. The density of a substance is expressed in C. G. S. units as *grams per cubic centimetre* and in F. P. S. units as *pounds per cubic foot.* The mass of 1 c.c. of pure water at 4°C is 1 gm. and so the density of pure water at 4°C is the unit of density in the C. G. S. system.

The **specific gravity** of a substance *is the ratio of the weight of any volume of the substance to the weight of an equal volume of some standard substance.* This standard substance in case of solids and liquid is taken to be pure water at 4°C and in case of gases hydrogen at normal temperature and pressure. The specific gravity being the ratio of two weights *is a pure number having no dimension* and is independent of any system of measurement.

The ratio of the mass of any volume of a substance to the mass of an equal volume of water at 4°C is the same as the ratio of the mass of unit volume of the substance to the mass of unit volume of water at 4°C. Hence specific gravity may be defined as the ratio,—

$$\frac{\text{Density of substance}}{\text{Density of water at } 4^\circ\text{C}}$$

For this reason, the Specific Gravity is often called the **relative density.** If ρ is the density of a substance, S its specific gravity and ρ_1 the density of water, then, $S = \rho/\rho_1$.

The value of ρ_1 in the C. G. S. system is 1 gm. per c.c. Thus the specific gravity of a substance in this system is numerically equal to its density. For example, if the specific gravity of a substance is 2·5, then its density is 2·5 gm. per c.c. In the F. P. S. system ρ_1 is equal to 62·43 lb. per cu. ft. at 4°C. Hence density of a substance on this system is the product of the specific gravity and 62·43 lb. per cu. ft.

Temperature Correction—In an experiment to determine the specific gravity, water at the room temperature is available and so

the *relative density* of the substance under investigation with respect to water at the room temperature is obtained. To reduce the value to the true specific gravity we have to take into consideration the density of water at 4°C. This may be done by the following way.

$$\text{Specific Gravity} = \frac{\text{mass of a certain volume of substance}}{\text{mass of equal volume of water at } 4^\circ C}$$

$$= \frac{\text{mass of certain vol. of substance}}{\text{mass of equl vol. of water at } t^\circ C} \times \frac{\text{mass of equal vol. of water at } t^\circ C}{\text{mass of equal vol. of water at } 4^\circ C}$$

$$= \text{Observed Specific Gravity} \times \text{Density of water at } t^\circ C.$$

Thus, on getting experimentally the value of apparent specific gravity with respect to water at the room temperature t°C, the density of water at the room temperature is to be known from the Table of Constants. The product of the two gives the true specific gravity.

It is to be noted that the apparent specific gravity and the true specific gravity ordinarily differ by less than 1% because the density of water varies by a very little amount for a moderate change of temperature. For this reason *temperature correction of specific gravity is not necessary for ordinary purposes unless otherwise mentioned.*

Date— EXPERIMENT 34

To Find the Specific Gravity of a Solid Body using Hydrostatic Balance

Theory—If the mass of a body in air be M_1 and in water be M_2 then the mass of water displaced is $M_1 - M_2$ The observed specific gravity of the body at the room temperature is, therefore, equal to

$$\frac{M_1}{M_1 - M_2}$$

Apparatus—A hydrostatic balance, weight box, piece of marble, some thread, a beaker and a thermometer.

[Here the description of a hydrostatic balance is to be given here and a sketch of the apparatus is to be drawn.]

Procedure—Raise the beam of the balance by turning the key and examine whether the pointer oscillates equally on both sides of the scale. If not, make preliminary adjustments of the balance according to directions given on pp. 60 Tie the supplied piece of marble with a piece of fine string of suitable length and suspend it from the hook of the left arm of the balance. Weigh the suspended marble piece in air twice and find the mean value of the mass.

Next place the rider table above the left pan so as not to touch it and put a glass beaker on the rider table such that the marble piece hangs within it without touching any side. Pour water slowly into the beaker to such level that the marble piece is completely immersed. Carefully examine whether any air bubble is sticking to the undersurface or crevices of the marble piece. If any bubble

sticks to it slowly move the piece in water to remove the bubble.* In the immersed state, find the mass of the marble twice and find the mean value. Tabulate the data and hence calculate the result. Take the temperature of water with a thermometer (if temperature correction is necessary).

Results—

No. of Readings	Mass of body in air $= M_1$	Mass of body in water $= M_2$	Mass of displaced water $M_1 - M_2$	Observed Sp. Gr. $\frac{M_1}{M_1 - M_2}$	Density of water at 24°C	Mean Corrected Sp. Gr.
	gm.	gm.	gm.		gm/c.c.	
1.	...	...	...	2·62		
2.	...	8·50	5·25	...	·996	2·61
3.	13·74	...	...	...		

Discussion.—Some error is introduced as the thread increases in weight by soaking a little water when the body is weighed in water. By using horse's mane in place of thread, this error would be eliminated. For a more accurate work, an equal length of mane or thread may be tied to the other end of the balance beam. Care should be taken that the body, while in water, does not touch any side of the beaker. Any air bubble sticking to the sides of the body under water entails an error in the measurement of its mass.

In ordinary method of weighing, an accuracy of mass upto a centigram is obtained. Hence density of water, correct to 3 places of decimals, makes a correction at the second place of decimals of the observed specific gravity.

Sp. Gr. of Bodies Lighter than Water

Since bodies lighter than water float on it, their weights in water cannot be taken directly. An insoluble heavy body, called a *sinker* is chosen such that when it is tied with the lighter body, the combination sinks in water. The mass of the sinker in water is first taken. Let it be W_1. Next the mass of the combination in water is taken. Let it be W_2. Then the mass of the lighter body in water is $W_2 - W_1$.

It is to be noted that a lighter body when immersed in water experiences an upward thrust due to buoyancy. So the weight W_2 of the combination in water is less than the weight W_1 of the sinker in water. Hence $W_2 - W_1$ which is the apparent weight of the body in water is a negative quantity.

Date—

EXPERIMENT 35

To Determine the Specific Gravity of a Solid lighter than Water using Hydrostatic Balance

Theory—If the mass of a body in air be W_1, the combined mass of the body and sinker in water be W_2 and the mass of the sinker alone in water be W_3, then the mass of the body in water is equal

* In case a few bubbles stick to the immersed body, due to buoyancy of the bubbles the weight of the body would be less.

to $W_2 - W_3$. Hence the observed specific gravity of the body at the room temperature is equal to

$$\frac{W_1}{W_1-(W_2-W_3)}=\frac{W_1}{W_1-W_2+W_3}$$

Apparatus—A hydrostatic balance, a weight box, piece of cork, a piece of brass, some thread, a beaker and a thermometer.

Procedure—Raise the beam of the balance and examine whether the pointer oscillates equally on either side of the scale. If not, make preliminary adjustments of the balance. Place the piece of cork on the left pan and weigh it as usual. Take three sets of readings for its mass and find its mean value. Tie it to the brass piece with a string and then weigh the combination in a similar way in water. See that no air bubbles are sticking to the combination in water. Take three such weights in water. If the body be porous, it should be boiled in water, before taking weight in water to get rid of air bubbles. Finally, take the weight of the sinker in water three times and find the mean. Note the temperature of water with a thermometer (if temperature correction is necessary).

Results—

Weight of the cork in air = (i)...gm., (ii) ...gm. Mean W_1 gm.

Weight of the combination in water = (i).. gm (ii) ... gm.
Mean W_2 gm.

Weight of the sinker alone in water = (i)...gm (ii) ... gm.
Mean W_3 gm.

$\therefore$ Sp. Gr. of cork at the room temperature $= \dfrac{W_1}{W_1 - W_2 + W_3}$

Temperature correction of the observed Sp. Gr. (if required)—
Temperature of water $= t°C$.
Density of water at $t°C$ as obtained from the Table $= D_t$

$\therefore$ Real Sp. Gr. of the cork $= \dfrac{W_1}{W_1 - W_2 + W_3} \times D_t$

Discussion—The same as of the preceding Experiment.

Sp. Gr. of Bodies Soluble in Water

If the substance under examination is soluble in water a liquid is to be chosen in which it is insoluble. Substances, which are soluble in water, are generally insoluble in oils. The relative density of the substance with respect to the liquid is to be found exactly as that of Experiment 27. Let it be D_1. If the relative density of the liquid with respect to water be D_2 (vide Expt 29), then the Sp. Gr. of the substance at the room temperature is $D_1 \times D_2$ as is evident from the following consideration.

Date— EXPERIMENT 36

To Determine the the Sp. Gr. of a Body Soluble in Water

Theory—If the relative density of a substance with respect to a liquid, in which it is insoluble, be D_1 and also the relative density of

that liquid with respect to water be ρ, then the specific gravity of the body with respect to water is given by the product of D_1 and ρ.

Apparatus—A hydrostatic balance, weight box, a beaker, a piece of alum, thread and some quantity of kerosene.

Procedure—The given piece of alum is weighed in air. It is then weighed in kerosene [for a detailed procedure vide Expt. 34]. The density of liquid ρ is supplied.

Results—

No. of Readings	Weight of alum in air M^1	Weight of alum in kerosene M_2	Weight of displaced kerosene M_1-M_2	Relative density $\frac{M_1}{M_1-M_2}$	Mean Density	Relative Idensity of kerosene ρ	Sp. Gr. of alum $\frac{M_1\rho}{M_1-M_2}$
	gm.	gm.	gm.				
1.	9·62	...	...	...	...		
2.	...	4·85	...	2·02	2·02	0·82	1·66
3.	...	...	4·76	...	...		

Discussions—The same as Experiment 34.

Specific Gravity of Liquids

To determine the specific gravity of a liquid, a solid body is chosen such that it sinks both in the liquid and in water and also it is insoluble in them. The body is first weighed in air; let it be M_1. Then it is weighed in the liquid; let it be M_2. It is finally weighed in water; let it be M_3.

The weight of displaced liquid having a volume equal to that of the body is evidently M_1-M_2. Similarly the weight of the displaced water having equal volume is M_1-M_2. Therefore the specific gravity of the liquid is equal to

$$\frac{\text{wt. of a volume of liquid}}{\text{wt. of equal vol. of water}}=\frac{M_1-M_2}{M_1-M_3}$$

Date—

EXPERIMENT 37

To Determine the Specific Gravity of a Liquid using Hydrostatic Balance

Theory—If the mass of a sinker in air be M_1 gm., in a liquid be M_2 gm. and in water be M_3 gm., then the specific gravity of the liquid is given by the expression.

$$\frac{\text{wt. of a volume of liquid}}{\text{wt. of equal vol. of liquid}}=\frac{M_1-M_2}{M_1-M_3}$$

Apparatus—A hydrostatic balance, weight box, a piece of brass, some thread, beaker, a quantity of turpentine oil.

Procedure—The brass piece is first weighed in air, then in water and finally in turpentine oil [For a detailed procedure vide Expt. 34].

Results—

No. of Readings	Mass of sinker in air $= M_1$	Mass of sinker in water $= M_2$	Mass of displaced water $M_1 - M_2$	Mass of sinker in oil $= M_3$	Mass of displaced oil $M_1 - M_3$	Sp. Gr. of oil $\frac{M_1 - M_3}{M_1 - M_2}$	Mean Sp. Gr.
	gm.	gm.	gm.	gm.	gm.		
1.	...	19 82	...	...	...	0·86	
2.	22·8	...	...	20·2	22 9	...	0·87
3.	...	...	2·67	...	...	...	

Discussions—The same as Expt. 34. The weight of the sinker in water should be taken earlier than that of oil, for the simple reason that it is often troublesome to clear the beaker and the sinker of oil.

Nicholson's Hydrometer

The word 'hydrometer' derives its name from Greek roots 'hydor' meaning 'water' and 'metron' meaning to measure. Originally a hydrometer was meant to find specific gravities of liquids. But now-a-days this apparatus is also used to determine specific gravities of solids and liquids. It consists of a *hollow* metal cylinder B connected at the top by a short thin stem M (Fig. 88). The stem carries a pan C and has got a round mark somewhere at its middle part. The lower end of the cylinder is connected to a conical piece L by a bent hook. The upper surface of the conical piece is shaped like a small pan so that a small object can be placed upon it. All the joints of the instrument are made water tight in order to prevent any liquid from entering into it. Suitable loads, such as lead shots or some quantity of mercury, is kept within the lower cone so that the instrument may float vertically on a liquid. It is a type of *constant immersion hydrometer* because in all experiments it is immersed always in a liquid at a constant height up to the mark on the stem. When the hydrometer floats on any liquid with a part of it submerged, then the mass of the liquid displaced by it is equal to the hydrometer.

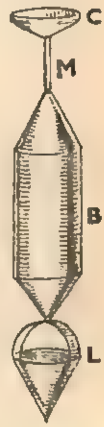


Fig. 88

Date—

EXPERIMENT 38

To Determine the Sp. Gr. of a Solid using Nicholson's Hydrometer

Theory—If W_1 be the weight necesary to sink the hydrometer upto the mark in pure water, W_2 be the weight when the body is on the upper pan and W_3 be the weight when the body is on the lower pan,

then the weight of the body in air $= W_1 - W_2$

The weight of the body in water $= W_1 - W_3$

Hence weight of displaced water $= W_1 - W_2 - (W_1 - W_3)$
$= W_3 - W_2$

$\therefore$ Sp. Gr. of the Body at Room temperature $= \dfrac{W_1 - W_2}{W_3 - W_2}$

If necessary, a temperature correction of Sp. Gr. may be made by multiplying the observed Sp. Gr. by the density of water at the room temperature.

Apparatus—Nicholson's hydrometer, weight box, a jar with an arrester and a piece of glass.

Procedure—Take a tall glass jar and fill it with pure water to near the brim. Lower the hydrometer slowly into water. It is found to float vertically with the whole of the stem projecting beyond the liquid surface (Fig. 89) See that the hydrometer does not touch the side of the jar nor any air bubble sticks to the hydrometer. If any air bubble is found, take out the hydrometer and rub gently the parts of its body with the liquid on which it is to float. Place suitable weights on the upper pan so as to sink the hydrometer upto the mark on the stem. Let the weights put on the pan be W_1. To avoid the risk that the hydrometer may not completely sink by too much over-loading, place a glass plate having a slot cut in it at the mouth of the jar. The stem passes through the slot but the upper pan is arrested by it. Sometimes a bent piece of wire is placed across the mouth of the jar for the same purpose.

Fig. 89

Next put a small fragment of a substance, of which the specific gravity is to be determined, on the upper pan and then place suitable weights upon it to sink the hydrometer upto the mark. Let it be W_2. Then raise the hydrometer from water and place the body on the lower pan and again float the hydrometer in water. Finally, with the body on the lower pan place weight on the upper pan to sink the hydrometer upto the mark. Let it be W_3. Repeat the experiment three times and calculate specific gravity from each set of observations. With a thermometer find the temperature of water and record the temperature. Let it be $t°C$.

Results—Body under examination is a piece of glass.

No. of Readings	Load W_1 on upper pan	Body and Load W_2 on upper pan	Body on lower pan Load W_3 on upper pan	Sp Gr. $\frac{W_1-W_2}{W_3-W_2}$	Mean Sp. Gr.
	gm.	gm.	gm.		
1	14·98	7·54	10·50	2·51	
2	...	7·53	...	2·50	2·51
3	14·99	...	10·51	2·51	

∴ Required Sp. Gr. of the given sample of glass = 2·51 at $t°C$.

Discussions—The solid taken must not be heavy enough to sink the hydrometer more than the mark on the stem. The hydrometer should not touch the sides of the jar while floating, not any air bubble should be sticking to the hydrometer while measurement is made. The temperature correction of the observed result may be

done, if required, by a method as previously stated. This method of measuring the mass of the body is less accurate than the hydrostatic balance method and hence the specific gravity as determined is subject to a greater percentage of errors.

There is one advantage with this method in measuring sp. gr. of lighter bodies inasmuch as no sinker is required to measure the weight of the body in water. The lighter body is tied to the lower pan with thread and its weight is measured in the usual way.

Date— EXPERIMENT 39

To Determine the Specific Gravity of a Liquid using Nicholson's Hydrometer

Theory—If the weight of a Nicholson's hydrometer in air be W_1, and if W_2 be the load required to sink it upto the mark in water and W_3 the load required to sink it in a liquid, then the specific gravity of the liquid is given by the expression

$$\frac{W_1 + W_3}{W_1 + W_2}$$

Apparatus—A Nicholson's hydrometer, a balance, a weight box, a glass jar, a quantity of kerosene and water.

[A description and sketch of the apparatus are necessary here.]

Procedure—Weigh the hydrometer in air with a physical balance correct to the nearest centigramme. Take two readings of its weight and find the mean. Let its weight in air be W_1. Then float it vertically on water in a jar taking care that the hydrometer does not touch the side of the vessel nor any air bubble sticks to it. Then beginning from the smallest weight in the box, by trial place suitable load on the upper pan to sink the hydrometer upto the mark. Take two such readings and find the mean. Let it be W_2. Then float the hydrometer on the liquid in a similar manner and place suitable load to sink the hydrometer again upto the mark. Take two such readings and find the mean. Let the mean weight be W_3.

Now by the principle of floatation $W_1 + W_3$ is the weight of liquid displaced by the hydrometer upto the mark. Similarly, $W_1 + W_2$ is the weight of displaced water having an equal volume.

Results—

Weight of the hydrometer in air $= W_1$ gm.
Weight required to sink the hydrometer in water $= W_2$ gm.
Weight required to sink the hydrometer in kerosene $= W_3$ gm.

$\therefore$ Required Sp. Gr. of Kerosene $= \dfrac{W_1 + W_3}{W_1 + W_2}$

Discussions—The hydrometer method for determining or comparing the specific gravities of liquids is not very accurate since it is not sensitive to a small variation of weights placed on its pan. It is also unsuitable for determining sp. gr. of the liquids *e.g.*, acid

solutions, which act upon the metal of the hydrometer.* For such liquids a specific gravity bottle or a U-tube is convenient. With ordinary Nicholson's hydrometer, the specific gravity as determined, is not correct beyond two places of decimals.

For a given liquid one hydrometer might be too heavy to sink of itself while another might be too light not to float vertically. Hence there are hydrometers of various weights to suit particular ranges of specific gravities.

Date— EXPERIMENT 40

To Determine Sp. Gr. of a Liquid with Nicholson's Hydrometer (Alternative method)

Theory—If W_1 be the weight necessary to sink the hydrometer in water upto the index mark with a body on the upper pan and W_2 be the weight required to do the same with a solid on the lower pan, then the weight of water having the same volume as that of the solid is given by $(W_2 - W_1)$. Similarly, if the experiment is repeated in a given liquid and W_3 and W_4 represent the corresponding weights, then weight of the liquid having the same volume as that of the solid is $(W_4 - W_3)$.

$$\text{Then Sp. Gr. of the Liquid} = \frac{W_4 - W_3}{W_2 - W_1}$$

Apparatus—A Nicholson's hydrometer, a weight box, a sinker, a glass jar, a quantity of kerosene and water.

Procedure—Fill the jar with pure water and float the hydrometer vertically in water taking care that it does not touch the side of the jar nor any air bubble sticks to it. Place suitable weights on the upper pan to sink the hydrometer upto the index mark. Then place the solid on the lower pan and add weights on the upper pan to sink it upto the required level. Take three sets of observations.

Then fill the jar with the given liquid and repeat similar operations. Finally, evaluate the mean value of sp. gr.

Results—

Weight required to sink hydrometer in water with body on upper pan $= W_1$ gm.

Weight required to sink hydrometer in water with body on lower pan $= W_2$ gm.

Weight required to sink hydrometer in liquid with body on upper pan $= W_3$ gm.

Weight required to sink hydrometer in liquid with body on lower pan $= W_4$ gm.

$$\therefore \text{ Required Sp. Gr.} = \frac{W_4 - W_3}{W_2 - W_1}$$

Discussions—Same as Expt. 39.

*Recently hydrometers have been constructed of glass and acid proof plastics which may be safely used with acids or acid solutions.

ORAL QUESTIONS

What is Archimedes' principle? State the condition of floatation of a body. Nicholson's hydrometer is made of some metal which is heavier than water; why then it floats on water? Why is the hydrometer loaded at the bottom. What precautions do you observe in using a hydrometer? Is it possible to find the specific gravity of all substances heavier or lighter than water with one Nicholson's hydrometer? Why should the hydrometer be always sunk upto a fixed mark?

Measurement of Specific Gravity of a Soluble Solid

When a piece of solid, which is soluble in water, is supplied, its specific gravity is measured with a Nicholson hydrometer in the following way. Take a jar and fill it with a liquid in which *the solid is insoluble.* Float the hydrometer and place a weight so that the hydrometer sinks up to the mark in this liquid. Let the weight be W_1 gm. Take out the weight and place the body on the upper pan. Then place a weight W_2 gm. such that the hydrometer sinks upto the mark. Then weight of the body in air $= W_1 - W_2$ gm.

Now place the body on the lower pan and put a weight to sink it upto the mark. Let it be W_3 gm. Then weight of the body within the liquid is $W_1 - W_3$ gm. Then the relative density of the body with respect to the liquid is ;

$$\frac{W_1 - W_2}{W_3 - W_2}$$

Then take out the hydrometer, dry it carefully and weigh it in a balance. Let the weight of hydrometer in air be W gm. Float it in pure water and find the weight necessary to sink it upto the mark in water. Let it be W_4. Then density of liquid with respect to water is

$$\frac{W + W_1}{W + W_4}$$

Hence the sp. gr. of the soluble solid with respect to water

$$= \frac{W_1 - W_2}{W_3 - W_2} \times \frac{W + W_1}{W + W_4}$$

The procedure, result and discussions are the same as in previous experiments.

Specific Gravity Bottle

The specific gravity bottle consists of a small flat-bottomed glass flask. It is provided with a ground glass stopper having a capillary bore all though its length (Fig. 90). If the bottle is completely filled with any liquid and the stopper is then carefully fitted, the excess of liquid escapes through the bore leaving a *constant volume* of the liquid. The temperature at which the volume is standardised is indicated on the outside of the bottle.

Fig. 90

In one type of bottle the internal capacity at a certain temperature is marked on its outside. In another type the mass of pure water completely filling the bottle at a temperature is indicated as in the figure. A specific gravity bottle is specially suited to measure the specific gravity of a solid in form of fragments or powder and of liquids.

Date—

EXPERIMENT 41

To Determine the Specific Gravity of a Liquid using a Specific Gravity Bottle

Theory—If W_1 is the weight of the empty bottle with its stopper, W_2 is the weight of the bottle with a liquid filling it completely, W_3 is the weight of the bottle with pure water filling it completely, then

$$\text{Sp. Gr. of the liquid at the room temp.} = \frac{W_2 - W_1}{W_3 - W_1}$$

Apparatus—A specific gravity bottle, a balance and a weight box, some quantity of glycerine, (say).

[A description and a diagram of a specific gravity bottle are necessary here.]

Procedure—Wash the bottle with its stopper with a solution of caustic soda, then with nitric acid and finally with distilled water. Dry the bottle by passing hot air into it and measure its weight W_1 with a balance. The method of oscillations should be used to get accuracy of weight upto the third place of decimals in grammes. Take the weight three times and get the mean value. Fill the bottle completely with pure water. See that no air bubbles are inside the bottle. If there is any, shake the bottle to remove air bubble. Then insert the stopper carefully. The excess water would flow out through the capillary bore of the stopper. Wipe the bottle dry on the outside parts and weigh it. Weigh the bottle with water three times and find the mean value. Let the mean weight of the bottle and water filling it be W_3. Then throw water out and dry the bottle again. Pour glycerine into the bottle to its brim, care being taken to see that no air bubble sticks inside. Insert the stopper and wipe the outside dry. It is weighed thrice and the mean weight W_2 is found. From each set of observation sp. gr. is calculated. The mean of all these values of specific gravity represents the sp. gr. of the liquid at the room temperature. Take a thermometer and record the temperature of water under experiment. Let it be t°C.

Results—

No. of Readings	Mass of bottle in air $= W_1$	Bottle + liquid $= W_2$	Bottle + water $= W_3$	Sp. Gr. $\frac{W_2 - W_1}{W_3 - W_1}$	Mean Sp. Gr. at t°C
	gm.	gm.	gm.		
1	...	62·801	...	1·263	1·262
2	12·622	...	...	...	
3	...	...	49·843	...	

The density of water at room temperature = ...

∴ Corrected Sp. Gr = 1·262 × ......

Discussions—Presence of air bubbles within the bottle specially when it is filled with a heavy oil or a viscous liquid is a source of

trouble. To remove air bubbles, the bottle is to be tapped gently while filling or sometimes it requires to be slightly heated. But in the latter case, the bottle should be allowed to come back to its original temperature either by a spray of water or by waiting for sometime. This is the most accurate method of measuring sp. gr. of a substance, since weight of the bottle can be taken very accurately.

Oral Questions

Why is a specific gravity bottle provided with a stopper having a capillary bore? What is the special utility of a specific gravity bottle? In another class of specific gravity bottle there is no stopper but there is a mark some where at the neck. Which form of the bottle would you prefer and why? What are the uses to which a specific gravity bottle is put to? Is temperature correction necessary in using a specific gravity bottle? What are the precautions to be taken when weighing the bottle with a liquid? What additional precaution is to be taken when working with a volatile liquid?

Date—

EXPERIMENT 42

To Determine the Specific Gravity of Solid using a Specific Gravity Bottle

Theory—If W_1 is the weight of the empty bottle with its stopper, W_2 the weight of the bottle with solid; W_3 the weight of the bottle, solid and pure water; W_4 the weight of the bottle and water filling it completely, then,

$$\text{wt. of solid in air} = W_2 - W_1$$

and wt. of water having a volume equal to that of the solid—wt. of the solid $= W_4 - W_3$

$\therefore$ wt. of water having a volume equal to that of the solid $= W_4 - W_3 + \text{wt. of solid} = W_4 - W_3 + W_2 - W_1$

$$\text{Thus Sp. Gr. of the Solid} = \frac{W_2 - W_1}{W_4 - W_3 + W_2 - W_1}$$

Apparatus—A specific gravity bottle, a balance and weight box, some glass beads.

Procedure—Cleanse the bottle and the stopper with caustic soda solution, then with dilute nitric acid and finally with water. Dry the bottle with hot air blast and find its weight in a balance with the method of oscillations. Take two sets of reading and find the mean weight, which is say W_1 Then put some powdered solid into the bottle, place the stopper as usual and then weigh it again in a similar way. Let the mean weight be W_2. Next with the solid inside the bottle, pour pure water into it until the bottle is full. Carefully insert the stopper and wipe out any liquid sticking to the outside. Measure the weight W_3 of the bottle and its contents. Finally take out the solid and fill the bottle completely with pure water. Put the stopper and weigh the bottle and water. Let this weight be W_4. Measure the temperature of water with a thermometer. Let it be t°C.

Results—

Weight of the empty bottle (i)......(ii) .....Mean = W_1 gm.
Weight of bottle and glass beads (i)......(ii) .....Mean = W_2 gm.
Weight of bottle + glass beads + water (i)......(ii)......Mean = W_3 gm.
Weight of bottle and water (i)......(ii)......Mean = W_4 gm.

$$\therefore \text{ Observed Sp. Gr. at a temp. } t°C = \frac{W_2 - W_1}{W_4 - W_3 + W_2 - W_1}$$

[Temperature correction of Sp. Gr. which is similar to that of other experiments may be done if required.]

Discussions—The determination of specific gravity involves the measurement of a few weights. Therefore each weight is to be carefully measured. When the bottle is filled with water, there should be no air bubble sticking inside the bottle, as this should entail an error in the determination of weight. When the bottle is filled with liquid, the outside of it should be wiped dry before weighing.

Oral Questions

What is meant by Sp. Gr.? Do you find the value of density of the substance by this experiment? Is temperature correction necessary in this experiment, if so why? What is according to your view a more accurate experiment—a hydrostatic balance or sp. gr. bottle method of measuring specific gravity? Supposing you are given a solid which is too big a lump to be introduced into the bottle; how can you find sp. gr. of this solid with the bottle? How can you measure sp. gr. of a solid soluble in water with this apparatus?

Date—

EXPERIMENT 43

To find the Length of a Coiled Wire by Hydrostatic Method.

Theory—If W_1 gm. be the weight in air of a sample of coiled wire and W_2 gm, the weight of the same in water, then the mass of displaced water is equal to $(W_1 - W_2)$ gm. If ρ be the density of water at the observed temperature, then the volume of displaced water is $(W_1 - W_2)/\rho$ c.c. which is evidently the volume of the wire. If α sq. cm. be the average cross-section of the wire and l be its length, then,

$$l\alpha = \frac{W_1 - W_2}{\rho} \text{ c.c. whence } l = \frac{W_1 - W_2}{\rho\alpha}$$

Apparatus—A hydrostatic balance, a glass beaker, a weight box, a sample of coiled wire and some thread.

Procedure—Tie the sample of coiled wire with a piece of fine thread and suspend it from the left arm of the hydrostatic balance. Find the weight of the coiled wire while suspended in air Take at least two sets of readings for its weight favourably by the method of oscillations. Let the mean weight be W_1 gm.

Next take some water in a beaker, and place the beaker upon the hydrostatic table so that the coil is immersed in water. If the coil consists of a fairly large number of close turns, there is every possibility of air bubbles sticking within the coil. To remove air

bubbles the coil should previously be placed for sometime in hot water before immersing it into the water of the beaker. Then measure the weight of the coil in water, following the method of oscillation, if possible. Take two such weights. Let the mean weight in water be W_2 gm.

Then find with a screw gauge the diameter of the wire at four or five regions and at each place take two readings at right angles to each other. Hence knowing the mean diameter, find the average cross-section. Then from the formula calculate its length.

To verify the result make the wire straight and measure its length with a metre scale.

Results—

The weight of the coiled wire in air $= W_1$ gm.

The weight of the coiled wire in water $= W_2$ gm.

$\therefore$ Weight of displaced water $= (W_1 - W_2)$ gm.

Hence volume of displaced water = volume of the given sample of wire $= \dfrac{(W_1 - W_2)}{\rho}$ c.c.

Direct determination of cross-section—

Pitch of the micrometer screw $= m$ cm.

No. of division on the micrometer head $= n$

$\therefore$ Least count of the instrument $= m/n$ cm.

Diameter of the wire = (i) d_1 cm. (ii) d_2 cm. (iii) d_3 cm. (iv) d_4 cm. (v) d_5 cm. (vi) d_6 cm.

$\therefore$ mean diameter $= d$ cm. and mean radius $= \dfrac{d}{2} = r$ cm.

$\therefore$ cross-section $= \pi r^2$ sq. cm.

Hence length of the wire $= \dfrac{W_1 - W_2}{\pi r^2 \rho}$ c.c.

The length of the given sample of wire using a metre scale = (i) l_1 cm. (ii) l_2 cm. (iii) l_3 cm. (iv) l_4 cm.

Mean length of the wire $= l$ cm.

Discussions—The direct determination of the length of the wire is more accurate than by the hydrostatic method. If the difference of the results be β cm. then the percentage of error is equal to $\dfrac{\beta \times 100}{l}$.

Care should be taken such that the coiled wire while in water does not touch the sides of the beaker.

Date—

EXPERIMENT 44

To find the Average Cross-section or Radius of a Wire by Hydrostatic Method

Theory—If a wire of length L cm. has a mass W_1 gm, in air and W_2 gm. in water and if the density of water be ρ gm. per c.c., then the volume of the wire is given by $\dfrac{W_1 - W_2}{\rho}$ c.c.

If further r cm. be the radius of the wire, then the volume of the wire $\pi r^2 L$ c.c.

$$\text{Thus } \pi r^2 L = \frac{W_1 - W_2}{\rho} \text{ whence } r = \sqrt{\frac{W_1 - W_2}{\pi \rho L}} \text{ cm.}$$

$$\text{and } \pi r^2 = \text{average cross-section} = \frac{W_1 - W_2}{\rho L} \text{ sq. cm.}$$

Apparatus—A hydrostatic balance, a weight box, a piece of straight wire, a glass beaker and some thread.

Procedure—Measure the length of the wire with a metre scale correct to the nearest millimetre. Repeat this procedure three times and find the mean length. Make a coil of this wire such that it can be easily introduced into the beaker supplied. Now suspend the coil by a thin piece of thread from the left arm of the balance and place an equal length of thread on the right pan. Measure the weight of this coil in air three times and find the mean weight in air.

Place the bridge above the left pan so that the pan beneath it is free to move. Now place the beaker on the bridge such that the coil hangs freely within the beaker. Pour water slowly into the beaker so as to immerse the coil completely. Then measure the weight of the coil in water three times and obtain the mean. Get the value of the density of water at the laboratory temperature from the Table of Constants.

Results—

The length of the wire (measured with a metre scale)
(i) 54·1 cm. (ii) 54·2 cm. (iii) 54·1 cm.
∴ Mean length = 54·1 cm.

Mass of the wire in air
(i) 1·41 gm. (ii) 1·41 gm. (iii) 1·42 gm.
∴ Mean mass in water = 1·41 gm.

Density of water at 28°C = 0·995 gm. c.c.

Then the average cross-section of the wire

$$= \frac{1{\cdot}59 - 1{\cdot}41}{{\cdot}995 \times 54{\cdot}1} = \frac{{\cdot}18}{{\cdot}995 \times 54{\cdot}1} = {\cdot}0033 \text{ sq. cm.}$$

$$\text{Also radius of the wire} = \sqrt{\frac{0030}{3{\cdot}14}} = {\cdot}03 \text{ cm.} = {\cdot}3 \text{ mm.}$$

Discussions—The radius or the area of cross-section, as measured hydrostatically, is rather an indirect and round about process. The measurement of diameter by callipers or screwgauge is more accurate no doubt. But the experiment is here only to utilise Archimedes' principle for volume determination and thence to calculate the radius or area of cross-section.

Variable Immersion Hydrometers

The apparatus consists of a hollow uniform glass stem S attached to another hollow glass piece H ending in a bulb B (Fig. 91). The instrument is loaded with some mercury or lead shots at its lowest part so as to float on a liquid vertically with a part of the stem above it. A hydrometer floats on different liquids with different lengths of the stem exposed. The stem is graduated and the reading of the level of the liquid gives the specific gravity of the liquid directly.

Fig. 91

The instrument is calibrated by floating it on liquids of known specific gravities. The sp. gr. of pure water at 4°C is taken to be 1000 which is to be read as 1·000. In a denser liquid the hydrometer floats out to a greater extent and hence for determination of specific gravities of liquids heavier than water, the graduations are to be made from the top downwards as is shown in the Fig. 91*a*. Suppose that the reading of the instrument is 1650 in a liquid, which indicates that the specific gravity of the liquid is 1·650. On the other hand a hydrometer of this type sinks more and more in lighter liquids. Hence for the determination of sp. gr. of lighter liquids the graduations are made from the bottom of the stem upwards as is shown in the Fig. 91*b*. Suppose that the reading of instrument is 920 in a liquid : it means that the specific gravity of the liquid is 0·920. As this class of instruments works upon the principle of floatation to different extents in different liquids they are called *variable immersion hydrometers*. Since, in any measurement, no extra load is attached to such instruments, they are also called *constant weight hydrometers*.

The same instrument is not used for all ranges of specific gravities. A set of variable immersion hydrometers is provided in a box, usually five to six in number, for a range of specific gravity from 0·5 to 2·0.

U-tube Method

The apparatus consists of a long U-tube of glass fixed upon an wooden frame such that the two arms remain vertical (Fig. 92). There is a scale fixed alongside the limbs. It can be conveniently used to compare the relative densities of two liquids which do not mix with each other nor have any chemical action.

To compare the densities of two liquids, one of them, generally the heavier, is poured into the U-tube through an open end till it occupies nearly half the length of each limb. Then the other liquid is poured to nearly the top of one limb, and the combination is allowed to become steady as shown in the figure. Then the free

surfaces of the liquids at A and C as also the surfaces of contact at B are read off from the scale. If the difference of readings at A and B be h_1, and the density of the liquid occupying this volume be ρ_1, then the hydrostatic pressure at $B = h_1\rho_1 g$ [Vide Basu & Chatterjee's Intermediate Physics, Part I. Chap. X] The vertical height of the other liquid above the common surface of separation is the difference of the readings at C and B. Let this height be h_2 and the corresponding density be ρ_2. Then the hydrostatic pressure at the same horizontal plane as at B is $h_2\rho_2 g$. Then for equilibrium

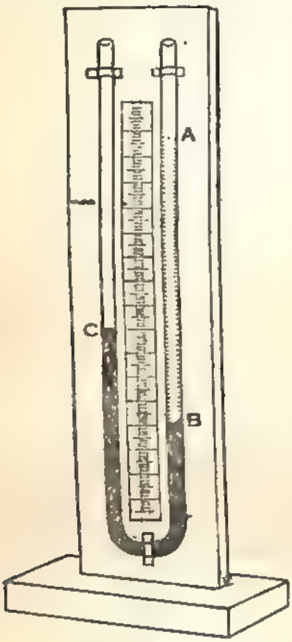


Fig. 92

$$h_1\rho_1 = h_2\rho_2 \qquad \text{or,} \qquad \rho_1 = \frac{h_2}{h_1}\rho_2$$

Suppose that the liquid in the column AB is water; then ρ_1 is equal to unity and ρ_2 may be directly calculated. It may be noticed in the equation that densities are inversely proportional to the heights of liquids from their surfaces of contact.

Hare's Hydrometer

It is also an apparatus to compare the relative densities of two liquids. It consists of an inverted glass U-tube fixed to a suitable stand. Two liquids from two pots are drawn up into two vertical limbs of the U-tube by sucking out air through another connecting pipe. Since the liquids rising up are not in contact, they cannot mix nor chemically react with each other.

Date— EXPERIMENT 45

To Compare the Densities of two Liquids with a Hare's Hydrometer

Theory—If h_1 is the height of a liquid column in one arm of a Hare's hydrometer, ρ_1 the density of the liquid, and if h_2 and ρ_2 denote the corresponding quantities for a second liquid in the other arm, then

$$h_1\rho_1 = h_2\rho_2 \qquad \text{or,} \qquad \frac{h_1}{h_2} = \frac{\rho_2}{\rho_1}$$

Apparatus—A Hare's hydrometer, pure water and a sample of copper sulphate solution.

The Hare's apparatus consists of an inverted U-tube of glass having two long vertical limbs (Fig. 93). The U-tube is fixed to an wooden board. A short glass tube connected at the topmost part is provided with a rubber tubing T. A pinch cock C fitted with the tubing can be operated to open or close the tube whenever necessary. Two graduated scales are fixed alongside the limbs and

are used to measure the heights of the two liquids under investigation.

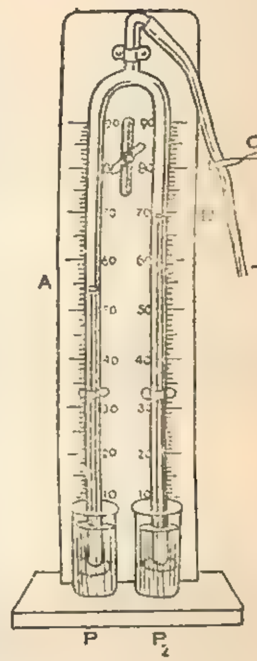


Fig. 93

Procedure—If found dirty, wash the U-tube with water a few times by placing two pots containing water under two limbs and sucking air out of the rubber tubing Each time air is sucked out, water is seen to rise up in the tubes. On releasing air, water flows down into the pots. After washing the tubes, remove the pots and blow air through the tubes to dry them.

Next pour the liquids to be tested in two pots and place them under the two limbs of the U-tube. Now draw out air through the upper tube when the liquids are seen to rise up to different heights A and B (say). Then close the pinch cock C so as to stop the air passage of the rubber tubing. If now the liquid surfaces are found to descend slowly, there must be a leakage of air into the apparatus. This leakage must be stopped either by grease or by knots of thread at the glass rubber joints. When the liquid columns become stationary, measure from the attached scale the length of the liquid columns above the free surface of the liquid in each pot. Take a number of readings for each liquid column at intervals of a minute. Suck the liquids five times to different heights and tabulate the readings.

Results—

No. of Reading	Liquid level in P_2 cm.	Level at A cm.	Length of column h_2 cm.	Water level in P_1 cm.	Water Level at B cm.	Length of column h_1 cm.	Ratio h_1/h_2
1	6·7	54·8	48·1	5·8	69·5	63·7	1·3
2	...	...	...	...	...	...	...
3	6·8	...	39·5	...	...	...	1·3
4	...	...	...	...	...	...	...
5	...	50·2	...	5·85	...	...	1·3

Discussion—The mean value of the ratio is found to be 1·3. Hence sp. gr. of the sample of copper sulphate solution is also 1·3. There should not be any leak anywhere within the tubes and the pinch cock should be tightly pressed every time before taking readings. Temperature correction of density is not necessary, since both the liquids undergo a nearly equal variation of density due to a change of temperature. The level of a liquid within the pot at the region

where the glass tube is dipped is higher than usual due to capillary action. Consequently a measurement of the height of any liquid within the U-tube with a separate metre scale entails some errors. To avoid this a metal needle or a pointer is often fixed vertically so that its tip just touches the liquid surface within the pot at some distance from the U-tube. The vertical height from the tip of this pointer to the level of liquid in the tube marks the height of the corresponding liquid column.

Oral Questions

What is the principle on which a Hare's hydrometer works? Does it differ from that of a variable immersion hydrometer, how? What are the conditions of floatation of a body? Why does a liquid run into a limb of a Hare's hydrometer, when air is sucked out? Can a liquid be run to any height by this sucking process? Why do different liquids rise to different heights? Is it essential that the limbs of the hydrometer should be vertical? If not, how can the correction for the liquid column be made?

Sp. Gr. of Bodies by the Method of Floatation.

Whenever a body floats freely on a liquid, the weight of the body is equal to the weight of the liquid displaced. If the body be a cube, a rectangular parallelopiped or a cylinder such that the volume is proportional to height or length, its specific gravity can be conveniently measured in the following way.

Suppose that a body of uniform cross-section a has got a length l. Then its volume is la. If the sp. gr. of the body be S and density of water be ρ, then the mass of the body is $la\,S\,\rho$. If it floats on water with a height e exposed, then the part submerged is $(l-e)$. The submerged portion has got a volume $(l-e)\,a$ and this volume of water has got a mass $(l-e)\,a\rho$. By the principle of floatation,

$$laS\rho=(l-e)\,a\rho \text{ whence } S=\frac{l-e}{l}=\frac{\text{height submerged}}{\text{total height}}.$$

Date—

EXPERIMENT 46

To Determine the Sp. Gr. of a lighter Body by the Method of Floatation

Theory—If a body of the shape of a cylinder or rectangular parallelopiped floats vertically on water, then the specific gravity of the body is given by the ratio—

$$\frac{\text{Height of the body below water}}{\text{Total height of the body}}$$

Apparatus—A trough, a cylindrical block of wood slightly loaded at the bottom, a glass cover plate, a metre scale and a pin.

Procedure—Pour water into the trough until it is a about *half-full*. Float the given block on water and place the glass plate on the trough so as to cover a portion of it.

Fix a pin at the end of the metre scale. Hold the meter scale *vertically* so that the end of the pin *just touches* the surface of water in the trough. Take the reading of the metre scale against the upper surface of the glass plate. Record three such observations at different positions of the plate and find the mean value. Next place the scale vertically such that the pin just touches the upper surface of the cylindrical block and record a similar set of readings against the glass plate. The difference of the two sets of readings is the portion of the cylinder above the surface of water.

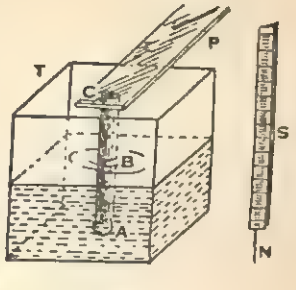


Fig. 94

Take out the cylinder from the liquid and measure its length three times and take the mean. Thus knowing the total height and the *height submerged*, calculate the specific gravity.

Results—

No. of Readings	Surface of water cm.	Mean cm.	Surface of block cm.	Mean cm.	Height above water surface cm.	Height of Block cm.	Mean height cm.	Height sub-merged cm.	Sp.Gr.
1	11·8	11·3	9·4	9·4	2·9	8·2	8·2	5·3	5·3
2	11·3		9·3			8·25			8·2
3	11·25		9·4			8·2			=0·65

Discussions—The different samples of wood have got different specific gravities ranging from 0·6 to 0·8. It should be noted that this method is only applicable to lighter bodies having a regular form. The readings for the upper surface of the block when floating on water should be carefully measured, since a slight pressure on piece depresses it below water.

ORAL QUESTIONS

What is meant by sp. gr. of a body? If the sp. gr. of a body is less than unity, why does it float? What determines the stability of a floating body? What shape of a body is suitable for determination of specific gravity by the method of floatation and why? If the body be of irregular shape but lighter than water, what method do you suggest to find its sp. gr.? What is Archimedes' principle and how can it be applied to determine the density of a body?

Date—

EXPERIMENT 47

To Determine the Sp. Gr. of a lighter Body by Displacement method

Theory—If a body while floating on water displaces a volume V_1 of the liquid at a particular temperature and if the body while completely immersed in water at the same temperature displaces a volume V_2, then the specific gravity of the body is given by the ratio of V_1 and V_2.

Apparatus—A piece of wood, a measuring cylinder having graduation of 0·1 c.c., a rod provided with three pins at its head.

Procedure—Some quantity of water is poured into the measuring cylinder and its volume is read. The piece of wood is then carefully placed upon water so as not to splash or sprinkle it. The solid displaces its own *weight* of water. The surface of water is now read. The difference of these readings gives the volume V_1 of water displaced. If the density of water at this temperature be ρ, then the mass of wood is $V_1 \times \rho$.

The piece of wood is then held at its top in a stable position by means of three pins projecting from the rod and is slowly *immersed wholly* in water. The water level is read. The difference of the 1st and 3rd readings gives V_2 the volume of water displaced by the body when completely immersed. Hence $V_2 \times \rho$ gives the mass of water having a volume equal to that of body. Hence the ratio of the mass of the body to the mass of equal volume of water is the same as V_1/V_2.

Result—

No. of Readings	First level of water	Second level of water	Difference $=V_1$	Third level of water	Difference $=V_2$	Ratio V_1/V_2	Mean Ratio = sp. gr.
	c.c.	c.c.	c.c.	c.c.	c.c.		
1	16·1	20·3	4·2	22·7	6·6	0·64	0·64
2	20 2	...	...	...	6·7	0·63	
3	...	...	4·2	28·3	...	0·64	

Discussions—The volume of the substance under investigation should be such as to displace a fairly measurable quantity of liquid to ensure a good result. The graduations of the measuring cylinder should be ·1 c.c. or even less. The substance should be dipped under the liquid very slowly as not to disturb the level of the liquid. The substance must not be porous as then air bubbles within pores will vitiate the results. Air bubbles must be removed by putting the substance under boiling water for sometime.

Pressure of Air

The fact that air has weight can be demonstrated by the following experiment. Take a glass globe fitted with an air-tight stop-cock. Take an air-pump and connect a rubber pressure tubing between the pump and the nozzle of the globe. Operate the pump for some considerable time and *close* the stop-cock. Now disconnect the globe and carefully weigh it in a balance. Record the mass of the globe, which is now almost vacuous. Then open the stop-cock to re-admit air. Weigh the globe again. An increase in weight proves that air has got weight.

The atmosphere envelopes the earth completely and extends two to three hundreds of miles above the surface of the earth. The density of the atmospheric air decreases with height. The atmosphere may be supposed to be divided into a large number of layers parallel to

the earth's surface. Any such horizontal layer of air has got to support the total weight of all the layers of air above it and is thus subjected to a downward force caused by their weight. Such a force acting upon unit area at any region is called *atmospheric pressure.* Since pressure in a fluid is transmitted equally in all directions, the amount of the atmospheric pressure is the same at a point in any direction. There are many experiments to show that air exerts pressure. (Vide Basu & Chatterjee's Intermediate Physics Part I, Chap. XI).

Rise of Liquid in an Exhausted tube

It is a matter of common experience that if one end of an open pipe is placed in water and air is sucked of the other end, water gradually rises up within the pipe. For a similar reason when one end of a syringe is kept in water and its piston is pushed up, water rises within the syringe. The reason is that on the free surface of any liquid atmospheric pressure acts in a vertically downward direction. When an open pipe is partly dipped into the liquid and some air is taken out, the pressure of air within the pipe falls below that of the outside air. Consequently, the pressure at all points on the surface of the liquid becomes unbalanced and to equalise the pressure, some liquid rises up within the pipe to such a height that the residual air presure within the pipe plus the liquid pressure on the surface of the liquid becomes equal to the atmospheric pressure.

Ultimately when all the air from inside the pipe is taken out, the internal air pressure within it is nil and the liquid rises to the maximum height within the pipe. The pressure due to the liquid column is then equal to the atmospheric pressure. If h represents the *vertical height* of the liquid column above the free surface of the liquid, ρ the density of the liquid and g the acceleration due to gravity, the hydrostatic pressure due to this column which is equal to the atmospheric pressure is given by the expression $h\rho g$. If two liquids of densities ρ_1 and ρ_2 are raised up in two vertical interconnected pipes to heights h_1 and h_2 then, since the external pressure is the same, $h_1\rho_1 = h_2\rho_2$.

$$\text{or,}\quad \frac{h_1}{h_2} = \frac{\rho_2}{\rho_1}$$

in other words heights to which different liquids rise are inversely proportional to their densities. Mercury is 13·6 times denser than water. So if these two liquids are sucked up in two pipes by exhausting air, water column will be 13·6 times longer than that of mercury,

Torricelli's Experiments

To make the experiment take a thick walled glass tube closed at one end and about a metre in length. Dry the inside of the tube with a current of hot air. Take some mercury in a basin and if the mercury surface is found dirty, take a filter paper and rub its surface. Then pour some dilute hydrochloric acid on its surface and

stir mercury and acid with a clean glass rod. Pour out the acid from above mercury or suck it out with a pipette.

Completely fill the tube with mercury. Close the open end tightly with a small glass plate or thumb taking care that no air bubble sticks inside. Now invert the tube *vertically* over a trough containing mercury such that the open end is under the surface of mercury. The mercury within the tube comes down to a certain extent and then becomes stationary. Measure the height of the mercury column from the mercury surface of the trough. The height would be found to be approximately 76 cm. or 30 inches.

The explanation of this fact is simple. When the tube, completely filled with mercury, is inverted vertically over the trough, the liquid pressure on the base of the mercury column is due to the height of the column. The atmospheric pressure acts over the exposed parts of the surface. For equilibrium these two pressures must be equal and opposite. When the tube is wholly filled, the pressure due to the mercury column is greater; so mercury from the base of the tube moves away and the level of mercury falls down. Ultimately a level is reached when the pressure due to the steady mercury column within the tube becomes equal to the atmospheric pressure. The space above mercury within the tube contains nothing but a little mercury vapour and is called the Torricellian vacuum.

It must be remembered that the pressure of a liquid depends upon the vertical height of the liquid column but not upon the area of the base on which the column stands. Therefore, whatever might be the cross-section of the tube a liquid stands at a constant height within it. A measure of the height of the column gives the magnitude of atmospheric pressure.

Date—

Experiment 48

To Read a Fortin's Barometer in Inches and Centimetres

Theory—The height of the mercury column in a barometer tube above the free surface of mercury in the reservoir, is a measure of the atmosheric pressure when the tube is placed vertically.

Apparatus—A Fortin's barometer.

The apparatus consists of a straight thick walled glass tube closed at the top and standing vertically over a cistern of mercury (Fig. 95). The glass tube is enclosed all through its length by a metal tube T which is marked black in the figure. Except for a little space at the top, the tube is filled with pure dry mercury. The space above mercury within the tube contains nothing but a little mercury vapour. The bottom of the tube is open and is inverted over a reservoir containing mercury. This part is also shown separately in a sectional diagram in Fig. 96. The upper wall of the reservoir is a glass cylinder G through which the surface of mercury can be seen. The middle of the cylinder is made of box-wood and is surrounded by a brass cylinder D. A piece of flexible leather B forms the base of the reservoir. The leather bag is provided with

an wooden button to which is attached the upper end of a screw S. By working this screw the leather bag can be raised or lowered so that the level of mercury within the reservoir can be adjusted at will. A piece of thin leather is attached at the top of the reservoir, through the pores of which the atmospheric pressure can act upon the inside mercury surface. A small ivory pointer P is fixed vertically to the lid of the reservoir. The lower end of the pointer forms the zero of the vertical scale attached to the barometer.

The lower end of the tube is made narrower. The advantage of making it narrower is that, the disturbances on the mercury surface while its level is being altered, would be damped quickly. The tube at the upper part is made broader to reduce the effect of surface tension. Two long slits are cut near the top of the metal casing. The slits are covered by two glass pieces so that the upper level of mercury can be seen through them. Two scales, one graduated in centimetres and other in inches, are engraved on the brass tubes along the two edges of the front of slit. Since the upper level of mercury is always to be read, the scales are graduated only at their top parts. To ensure accuracy in reading, a brass vernier scale V is provided with the main scale and the vernier scale can be slided up and down the slit by a rack and pinion arrangement worked by a screw R. To read the atmospheric temperature a mercury thermometer E is fixed with the brass body. The whole apparatus is suspended vertically on an wooden frame which is fixed permanently to a wall.

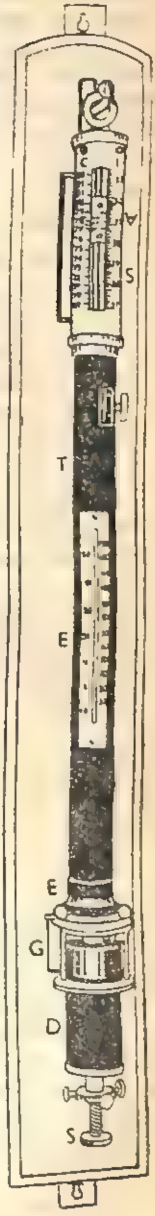


Fig. 95

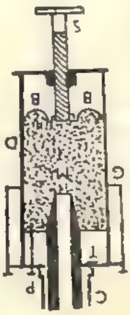


Fig. 96

Procedure—Look through the glass walls of the mercury reservoir to the ivory pin and observe whether the pin point is actually touching the mercury surface If not, turn the screw S in a proper direction until the image of the pin point on the mercury surface and the pin itself just touch each other. At this position the mercury surface just touches the point of the ivory pin. This is called the zero adjustment of the mercury level of the reservoir.

Now slide the vernier at some convenient position of the main scale and count the total number of vernier divisions and that of the main scale divisions in coincidence. Hence find the vernier constant (vide pp. 26). Next move the vernier till the lower edge of the

vernier becomes tangential to the mercury surface. Take the vernier reading at this position. This gives the height of the mercury column above the surface of mercury within the reservoir. Take the readings of both sides of the vernier in centimetres and in inches (vide Expt. 4). Readjust the vernier and take fresh sets of readings. Again readjust the mercury surface of the reservoir and take readings after fixing up the position of the vernier. Take the temperature as indicated by the thermometer attached to the barometer. Tabulate the data as indicated and calculate the mean barometric height.

Results—

Determination of Vernier Constant :

(i) Centimetre scale :
Let 20 vernier divisions = 19 main scale divisions.
Vernier const. = 1 main scale − vernier scale =
value of 1 m.s. = 0·1 cm. ∴ Vernier constant = 0·005 cm.

(ii) Inch scale :
Let 25 v.s. = 24 m.s.
or, Vernier constant = m.s. − 1 v.s.

Measurement of Height of Barometeric column at Calcutta at 26°C on the date of Experiment.

Scale used	No. of readings	Main Scale (a)	Vernier Scale (b)	Fractional part $b \times l.c.$	Total Height	Mean Height	Ratio Inch,
		cm.		cm.	cm.	cm.	cm.
Centimetre	1	75 7	19	0·095	76·795	75 798	
	2	75·7	19	0·095	75·795		
	3	...	...	...	...		
	4	...	...	...	...		
	5	75·8	0	...	75·800		
		in.		in.	in.	in.	
Inch.	1	29·85	0	0	29·850	29·852	2·539
	2	29·80	24	0·048	29·848		
	3	...	...	...	...		
	4	...	...	...	...		
	5	29·85	1	0·002	29·852		

Discussions—Since the zero of each scale begins from the lowest point of the ivory pin, the surface of mercury in the reservoir should be made to touch the pin point every time before taking the vernier reading. The barometer tube should always be kept vertical ; the verticality may be examined with a plumb line.

To make a standard of measurement the observed reading may be corrected for temperature, height above the sea-level and latitude, if such corrections are required.

Temperature correction—The observed height of the mercury column varies with temperature due to expansion of the scale and change in the density of mercury. Let h_t be the barometric height as observed with a scale at t°C. If the graduation of the scale be

supposed to be correct at $0^\circ C$ and h_o be the corresponding reading of the scale at $0^\circ C$.

Then $h_o = h_t\ (1 + at)$

where a = coefficient of linear expansion of the material of the scale.

Again let ρ and ρ_t be the densities of mercury at temperatures $0^\circ C$ and $t^\circ C$. Then the atmospheric pressure is $h_t\ (1 + at)\ \rho_t\ g$ while if it were measured at $0^\circ C$, it would have been $h_o \rho_o g$

Hence $h_o \rho_o = h_t\ (1 + \alpha t)\rho_t$ or $h_o = h_t\ (1 + \alpha t)\dfrac{\rho_t}{\rho_o}$

But $\rho_o = \rho_t\ (1 + \gamma t)$ where γ = coefficient of cubical expansion of mercury.

$$\therefore\quad h_o = h_t \frac{1 + \alpha t}{1 + \gamma t} = h_t(1 + \alpha t)(1 + \gamma t)^{-1} = h_t(1 + \alpha t)(1 - \gamma t)$$

$$= h_t\{1 + (\alpha - \gamma)t\}$$

For brass scale, $\alpha = 0{\cdot}000018$ and for mercury, $\gamma = 0{\cdot}000181$

Thus $h_o = h_t\ (1 - 0{\cdot}000163t)$

For the particular experiment, $h_t = 75{\cdot}798$ cm. at $26^\circ C$

$$\therefore\quad h_o = 75{\cdot}798\ (1 - 0{\cdot}000163 \times 26)$$
$$= 75{\cdot}798 \times 0{\cdot}99576 = 75{\cdot}487 \text{ cm.}$$

Pressure in Absolute Units—A column of liquid of height h and density ρ, exerts a pressure $h\rho g$ where g denotes the acceleration due to gravity. Thus pressure is expressed in absolute unit.

In the particular experiment h after temperature correction is 76·487 cm. ; ρ for mercury is 13·595 gm./c.c. and g for Calcutta is 978 cm/sec^2. Hence atmospheric pressure after being corrected for temperature is equal to

$$75{\cdot}437 \times 13{\cdot}595 \times 978 \text{ dynes per sq cm.}$$
$$= 1003668{\cdot}599 \text{ dynes/cm}^2.$$

Ratio of the Units—The measurement of the barometric height in inches and centimetres provides a method of finding the ratio of the units of length. Since the same height is measured in both units, their ratio will give the ratio of the units. The last column of the table then gives the ratio of inch and cm. For the particular apparatus the ratio is found to be correct to 3 places of decimals.

ORAL QUESTIONS

What is meant by the pressure of the atmosphere ? Is it constant ? It not, why does it vary ? Why is mercury ordinarily used in the construction of a barometer ? What will be the advantage if glycerine or water is used as the barometric substance ? What is temperature correction of barometric height ? Is this correction absolutely necessary at all places and at all times ? A barometer is taken to an aeroplane which is flying at high altitude ; would the reading change ? Why is a thermometer attached to a barometer ? Why do you adjust the mercury level always to touch the ivory point ?

Date— EXPERIMENT 49

To Verify Boyle's law and to Draw P—V curve

Theory—The pressure p exerted by a given mass of a gas at a uniform temperature veries inversely as its volume v. In other words, pv = constant so long as temperature is constant.

Apparatus—A Boyle's law apparatus, a barometer.

A Boyle's law apparatus consists of a vertical wooden stand provided with levelling screws at the base (Fig. 97). A metre scale is fixed with the stand. There are in some instruments two vertical grooves on two sides of the scale. A uniform glass tube closed at one end is connected through a rubber tubing to another uniform glass tube open at both ends. A part of the closed glass tube, the whole of the rubber tubing and some part of the open glass tube are filled with mercury. The space within the closed tube above the surface of mercury contains air. The two glass tubes can be slided up and down the grooves and can be fixed at any position by suitable clamps.

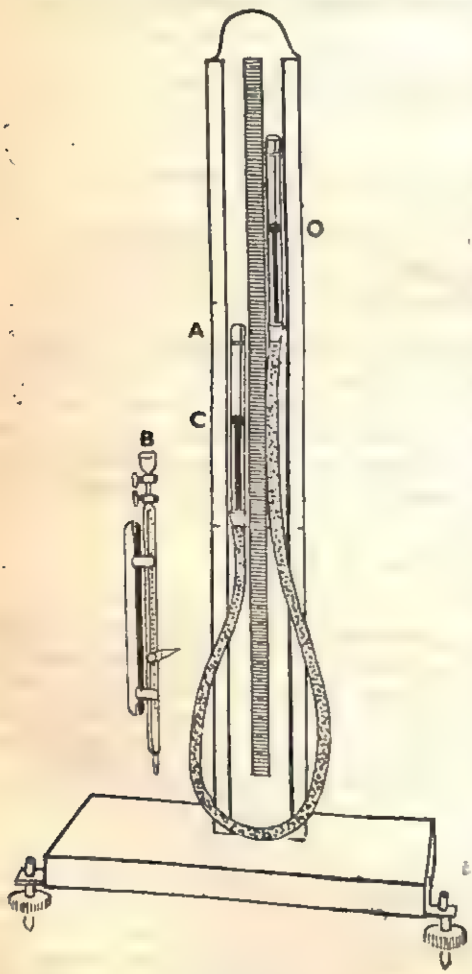


Fig. 97

In some modified instruments an extra attachment is provided with as shown separately to the left of the figure, which replaces the closed glass tube. The stop-cocks at the top allow the nature and mass of enclosed gas to be altered, if required.

Procedure—At the start take the barometer reading (vide Expt. 49). One or two readings may be sufficient. Place a spirit level on the bed of the Boyle's law apparatus and level the base by means of the screws attached to it. (For directions vide pp. 58). When the base is levelled, the stand carrying the metre scale and the tubes become automatically vertical. Then raise up or lower the glass tube with the open limb

till the mercury surface in the open limb and that in the closed limb come to the same level. At this position the scale reading for both the mercury surfaces should be the same. Take readings of the closed end A and the mercury level at C after waiting for a minute or two.* The difference of these two readings gives the length of the enclosed air column. Since the internal cross-section of the closed tube is uniform, the volume of the enclosed air is proportional to the length.

Then raise up the open tube slightly such that the mercury surface in this tube is at a higher level than that in the closed tube. After waiting for a minute or two take readings of the mercury surfaces at C and O with reference to the scale attached, correct to the nearest millimetre or a fraction of a millimetre by employing a magnifying glass. The reading of mercury level at O minus the reading at C gives the difference of the actual pressure of the enclosed gas and the atmospheric pressure. The volume of the enclosed air is evidently the difference of readings of A and C. Therefore, so long as the level at O is higher than that at C, the difference of readings is positive and the pressure of the enclosed gas is the *sum* of the atmospheric pressure and the differences of levels. In this way take three or four readings at pressures above the atmospheric pressure. When making any new adjustment of level, take care to wait for some minutes before taking a fresh reading; as otherwise there would be a fluctuation of the temperature and Boyle's law would not hold.

Next lower the open tube so that the mercury surface within this tube is at a lower level than that of the closed one. Measure the volume as before. In such a case the mercury level at O minus that at C is a negative quantity. Hence the enclosed gas pressure is equal to the atmospheric pressure *minus* the difference of levels. In this way take a few readings at pressures below the atmospheric pressure and tabulate the results. At the end of the experiment, take the barometer reading. The mean of the two barometer readings gives the average atmospheric pressure during the course of the experiment. Show the product of the pressure and volume in the last column. If the experiment is carefully done, the product for every pair of p and v would show nearly equal value.

Results—(A typical set of readings)
Barometric Pressure at the start of the experiment = 76·10 cm.
Barometric Pressure at the end of the experiment = 76·10 cm.
∴ Mean barometric pressure during the experiment = 76·10 cm.
Atmospheric temperature at the beginning of the expt. = 28°C.
Atmospheric temperature at the end of the expt. = 28°C.
∴ Mean Temperature = 28°C.

* Whenever a gas is quickly compressed, it becomes heated and temperature rises. Conversely when it is quickly expanded it becomes cooler.

No. of obs.	Reading at A $= a$	Reading at C $= c$	Volume of air $= a-c$	Reading at O $= o$	Difference of press. $= o-c=h$	Total Press. = Baro. press. $+h$	Volume × press. $= V \times P$
	cm.	cm.	cm.	cm.	cm.	cm.	
1	60·20	37·30	22·90	37·30	0·0	76·10	1742·7
2	60 20	38·10	22·10	40·75	2·65	78·75	1740·4
3	60·20	39 60	20·60	48 00	8 40	84·50	1741·7
4	60·20	40·10	20·.0	50·60	10·50	86·60	1740·6
5	60 20	36·20	24 00	32·70	−3·50	72·60	1742·4
6	60·20	34·90	25·30	27·60	−7·30	68·80	1740·6
7	60·20	33·75	26·45	23 50	−10 25	65·85	1741·7

The variation of volume with pressure is shown graphically in Fig. 98. Since $p \times v$ is constant, the graph is rectangular hyperbola. Again $p \propto 1/v$ and hence graphical relation of p and $/v$ would be a straight line.

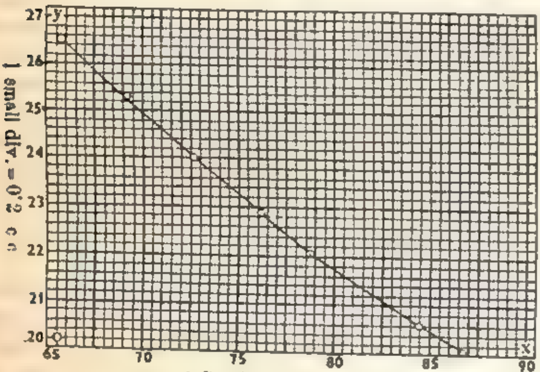


Fig. 98—Pressure-volume relation in Boyle's Law

Discussion—The product of the volume and the corresponding pressure is found to be fairly constant for a given mass* of the gas at the room temperature, the mean value for this particular mass being 1741. The cause of variation of the product is that we can read the volume and the difference of pressures correctly to 1 c.c, and 1 mm. and not more accurately. Further a slight variation of temperature during compression or expansion of the gas would cause a difference in the product of pressure and volume.

Oral Questions

What is Boyle's law? Why should the stand be made vertical? Why do you require the barometric pressure to verify the law? In what unit are you measuring the gas pressures? Would there be any effect, if the pressure is measured in a wider glass tube or in a non-uniform glass tube? Why in verifying Boyle's law, the volume of the gas should not be increased or decreased suddenly? What is the effect of a rise of temperature on an observed set of pv? What would be the effect on pv if the mass of gas is increased at a uniform temperature? Is the law true for all pressures and for all gases? What would be the effect on pressure-volume relation if the enclosed air contains water vapour?

*If the quantity of gas contained within the glass tube varies, the product pv would also vary.

Date— EXPERIMENT 60

To Determine the Atmospheric Pressure using a Boyle's Law Apparatus

Theory—If, in a Boyle's law experiment, P denotes the barometric pressure, h the difference of mercury levels in the *open* and *closed* limbs and v the volume of the enclosed gas,

then $(P+h)\propto\frac{1}{v}$ or, $h=\frac{K}{v}-P$, where K is a constant depending upon the mass of the gas and its temperature. During the course of the experiment, assuming P to remain constant, the relation between h and $1/v$ is linear.

Hence, when $\frac{1}{v}=0$, $P=-h$

Therefore, if a graph is drawn showing the relation between h and $1/v$, it would be a straight line and the intercept made by this line with the h-axis with sign changed will represent the atmospheric pressure.

Apparatus—A Boyle's law apparatus and a spirit level.

Procedure—Place a spirit level on the base plate of the Boyle's law apparatus and make the stand vertical with the base screws. Then by adjusting the height of the open tube bring the mercury levels in the open and closed tubes in the same horizontal plane. Now take the reading of the top of the closed glass tube which is, suppose, a. Next read the level of mercury surface within the closed glass tube; let it be c. Then $a-c$ represents a length which is proportional to the volume of the enclosed gas.

Lower the open end by a few centimetres, such that the difference of levels of mercury in the two limbs is 3 to 4 cm. Then after waiting for some minutes read the levels of mercury in the closed and open limbs and let them be c and o. Hence $o-c$ gives the difference of pressures h. In this way take a number of observations with a difference of levels at even steps of 4 to 5 cm. with negative values of h. Finally draw a graph with h and $1/v$ (Fig. 99)

Results—

No. of Readings	Reading at $A=a$	Reading at $C=c$	Volume of air $=a-c$	Reciprocal of volume	Reading at $O=o$	Difference of press. $h=o-c$	Atmospheric pressure
	cm.	cm.	cm.	c.c.$^{-1}$	cm.	cm.	cm.
1	60·20	37·30	22·90	·0436	37·30	0·0	75
2	60·20	36·20	24·00	·0416	32·70	−3·50	
3	60·20	34·90	25·30	·0395	27·60	−7·30	
4	60·20	33·75	26·45	·0378	23·50	−10·25	
5	60·20	32·10	28·10	·0356	17·90	−14·20	
6	60·20	30·80	29·40	·0340	13·90	−16·9	

Discussions—To be able to measure the atmospheric pressure correctly to a millimetre from the graph, the value of the smallest division on pressure axis should be at least one millimetre. This requires the graph paper to be so large as to contain a range of pressure difference from 0 to 80 cm. on the negative side. Such an extraordinary large graph paper is not ordnarily available. With the unit of measurement so chosen along the pressure axis (one smallest unit = 2 cm.) in Fig. 99, it is not possible to determine the pressure at B with an accuracy of less than 1 cm. of mercury. There is, however, a more accurate method of calculating the atmospheric pressure from any two known values of h which is given below.

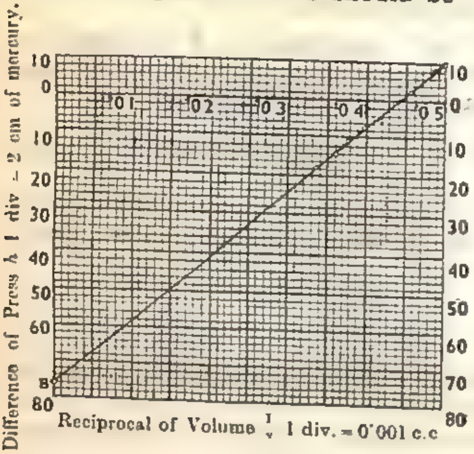


Fig. 99

Alternative Method—If P be the atmospheric pressure during the course of the experiment and h_1, and h_2 be two values for the difference of mercury levels in the *open* and *closed* limbs of the Boyle's law apparatus, then provided the temperature of the enclosed gas does not change,

$$(P + h_1)v_1 = (P + h_2)v_2$$

where v_1 and v_2 are the corresponding volumes of the enclosed gas. Knowing h_1, h_2, v_1 and v_2, P may be calculated. In practice atmospheric pressure is calculated separately from a number of pairs of h and the mean value of P is found. For example, taking the 2nd and 4th readings, $h_2 = -3·5$ cm., $h_2 = -10·25$ cm., $v_1 = 24·0$ c.c. and $v_2 = 26·45$ c.c.

$(P - 3.5) \times 24 = (P - 10·25) \times 26·45$ whence $P = 76·3$ cm,

From such calculations, it is possible to find the atmospheric pressure to the nearest millimetre.

Machine

A machine is a contrivance by which a force applied at a given point in it in a given direction may be made to appear at some other point in a different or same direction with a different magnitude. If the machine has got to do some work, this applied force whould have to move against an external resisting force. The force directly applied is called the **effort** and the resisting force overcome by the machine is called the **resistance**.

Velocity Ratio—The ratio of the distance d_1 through which the effort works to the distance d_2 through which the resistance is overcome is called the velocity ratio of a machine.

Thus velocity ratio

$$= \frac{\text{Distance through which applied force moves}}{\text{Distance through which resistance is overcome}} = \frac{d_1}{d_2}$$

Machanical Advantage—The mechanical advantage or *force ratio* of a machine is the number which expresses the ratio of the resistance overcome to the effort applied to the machine to produce equilibrium.

$$\therefore \quad \text{Mechanical Advantage} = \frac{\text{Resistance overcome}}{\text{Effort applied}} = \frac{P}{W}$$

Efficiency of a Machine—A part of the energy supplied to a machine is always utilised in overcoming frictional resistances within it and this part is wasted in form of heat. So useful work done by a machine is always less than energy supplied to it. The **efficiency** of a machine is defined to be the ratio of the useful work done by the machine to the total energy supplied to it. The efficiency of a machine is therefore less than unity and is often expressed as a percentage by being multiplied by 100.

[For details vide Basu & Chatterjee's Intermediate Physics, Part I General Physics, Chap. VI]

Date— EXPERIMENT 51

To Determine the Mechanical Advantage of an Inclined Plane when Effort is parallel to the Plane

Theory—The mechanical advantage of a machine is defined to be the ratio of resistance and effort, where resistance in the case of an inclined plane means the weight of any body placed on the plane supposed to have no friction with it, while effort means a force parallel to the plane just sufficient to hold the body at any point on the plane.

If P denotes the resistance and W the effort, then Mechanical

$$\text{Advantage} = \frac{P}{W} = \frac{\text{height of plane}}{\text{length of plane}}$$

Apparatus—An inclined plane, a metal roller, a scale pan, some thread and weights.

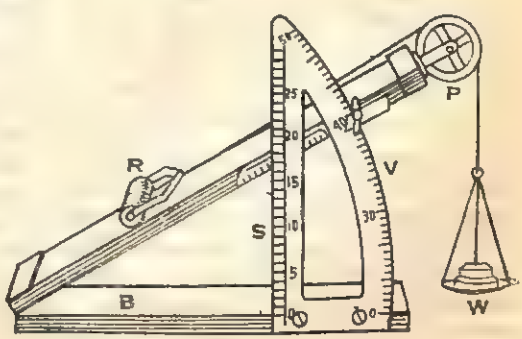


Fig. 100—Inclined plane

The apparatus consists of a smooth rectangular board A (Fig. 100) about 2 ft. in length and 4 inches in breadth hinged at one end to another similar board B so that they can be kept at any angle with each other. A sheet of glass is fixed upon the board to make the surface smooth. There is a straight vertical

scale S by which the height of the inclined plane above B can be measured. Some apparatus is provided with a circular scale V, as shown in the figure, by which the inclination of the plane of A may be directly measured in degrees.

A heavy and smooth metal roller R is provided with a hook to which is attached a string. The string runs parallel to the surface of the board and after passing over a smooth pulley P it carries a scale pan at the other end. A suitable load may be put upon the scale pan to start the up-gradient motion of the roller.

Procedure—At the start clean the board and the roller if found dusty or moist. Find the weight of the roller with its frame in a balance correct to nearest decigramme, Take the weight twice and find their mean. Let the mean value of the weight be P. Also find the weight of the scale pan in a similar way. Fix up the plane A to any convenient angle. Then tie a thin string between the roller and the scale pan and pass it over the pulley. Then holding the string in hand so as to prevent the roller from sliding down, add weights on the scale pan so as just to check the downward motion of the roller. Let the total load at the end of the string carrying the scale pan, including the mass of the scale pan, be P_1. Then slightly increase the load so as just to move the roller up the plane. Let the total load be P_2. The mean of these two loads may be taken as the equilibriating force P. Repeat the procedure thrice and take at least three readings of P for this particular slope of the plane. Change the inclination of the plane a few times and tabulate your observations.

Results—

No. of readings	Vertical height h inch.	Length of Plane l inch.	P_1 lb.	P_2 lb.	$P=\frac{1}{2}(P_1+P_2)$ lb.	Mass of roller W lb.	$\frac{h}{l}$	$\frac{P}{W}$	Percentage Difference
1	6	23·5	·74	·75	·745	3·1	·25	·24	4%
2	...	...	...	...	...	...	...	...	...
3	8	...	1·7	1·1	1·05	...	·34	·33	3%
4	...	...	...	...	...	...	...	...	...
5	10	...	1·3	1·35	1·32	...	·42	·43	2·5%

Discussions—The ideal values for mechanical advantage are the ratios of height of the plane to its length and for different inclinations these values are shown in the 8th column. The observed values are shown in the 9th column. The ideal values cannot be attained in the experiment due to friction at the pulley and the roller, although parts are designed to have a minimum friction. In a specially designed apparatus, the observed values are within 3 to 4% of the ideal values.

In some simpler from of apparatus, there is no circular scale. But there is a vertical upright in place of this upright. In this case

the vertical height h is measured with a metre scale and the angle between the boards is obtained from the tangent of that angle.

ORAL QUESTIONS

Define velocity ratio and mechanical advantage. What is the relation between velocity ratio and mechanical advantage in an ideal machine? What are effort and resistance in a machine? What is the necessity of having as little friction as possible in an inclined plane apparatus? What is the mechanical pdvantage of an inclined plane? How can you support efficiency of a wedge or a jackscrew from the standpoint of an inclined plane?

Friction Brake

The friction brake is, in principle, a method by which the work done by a machine in a definite interval of time may be estimated by employing some sort of friction. In simple form, the apparatus consists of a leather rope or belt B carrying a stout spring balance S or an equivalent apparatus at one end and a load of known mass W at the other. (Fig. 101).

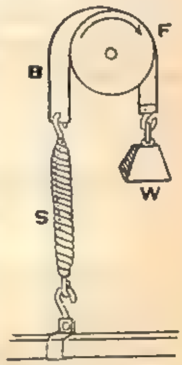


Fig. 101

The spring balance is fixed to a rigid support and the belt is slipped over the flywheel F of the machine. When the machine does not run, the flywheel is stationary, and the spring balance records a force in some units equal to the weight of the load, of course neglecting the mass of the belt. Now supposing that the flywheel is perfectly smooth, there is no friction between the belt and the rim of the wheel. In such a case the spring balance would record the same weight even if the fly wheel is running.

But in reality there is always some friction coming in and when the machine runs at some *constant speed* in the direction of the arrowhead the spring balance would record a force *greater* than the weight of the load. Let the reading of the spring balance be T and the weight of the load be M, both in *pounds weight*, when the flywheel runs at a speed of n revolutions per minute. The force of friction is $T-M$ pounds weight. If the radius of the flywheel is r in feet, then the circumference of the wheel is $2\pi r$ ft. In one revolution the force of friction moves through a distance $2\pi r$. Thus work done W in one revolution is given by,

$$W = 2\pi r(T-M) \text{ ft. lbs.}$$

The power is the amount of work per unit interval. Any point on the rim of the wheel moves through a distance $2\pi rn$ ft. in one minute.

$$\text{Power of the machine} = 2\pi rn(T-M) \text{ ft. lbs. per minute.}$$

Since one Horse-Power is 550 ft. lbs. per sec., the horse-power (H.P.) of the machine is given by,

$$\text{H.P.} = \frac{2\pi rn(T-M)}{60 \times 550} \text{ in F.P.S. units.}$$

If the power in *watts* is required, since 1 H.P. = 746 watts and 1000 watts = 1 kilowatt,

$$\text{H.P.} = \frac{2\pi rn(T-M)}{33000} \times \cdot 746 \text{ in kilowatts (C.G.S. units.)}$$

Date— **EXPERIMENT 52**

To determine the Horse-Power of an Electric Motor at normal Load

Theory—If r be the radius of the flywheel or the coupling wheel of a motor and if it runs at at a normal speed of n revolutions per minute with a brake force of P lbs. then the horse-power (H.P.) of the machine is given by,

$$\text{H.P.} = \frac{2\pi rn\text{P}}{33000}$$

Apparatus—An electric motor designed to run at a speed of 720 r.p.m., friction brake apparatus, a speedometer calibrated in r.p.m.

The friction brake apparatus consists of a stout and heavy base AB to which two vertical uprights CD are rigidly fixed. The uprights carry a crossbar EF which can be slided up or down and clamped anywhere (fig. 102). Two spring balances S_1 and S_2 calibrated in pounds weight are hung up from the cross bar with two adjustable blocks. The lower ends of the balance carry hook to which belts of suitable sizes can be fastened. The base carries screws and bolts for the fixing up the motor M under observation.

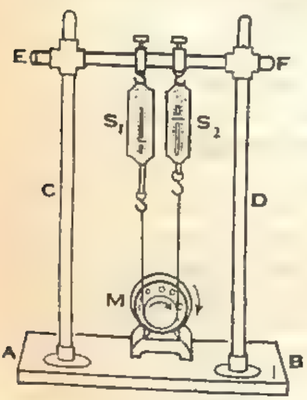


Fig. 102

Procedure—At first fix up the motor rigidly to the base AB if necessary. Then turn the switch on and examine whether the motor runs at no load. Disconnect the switch. Connect the speedometer to the shaft and adjust the height of the crossbar so that the belt lightly presses upon the flywheel.

Now turn on the switch again and observe the speedometer, which would generally record a higher speed of revolution with no load, now indicates lower speed with increasing load. Slowly raise the crossbar and observe the readings of the speedometer. When the speedometer indicates the correct speed, clamp the crossbar. Then take the readings of the spring balance. Readjust the crossbar and repeat the observations when the speedometer gives the correct reading.

Results—(A typical set of results given here.)

Diameter of the flywheel = 6 inches. ∴ radius = ·25 ft.

Speedometer reading in r. p. m.	Reading of balance S_1 lb.	Reading of balance S_2 lb.	Difference of readings lb.	Observed H. P.	Mean H. P.
720	2·2	14·6	14·6	0·49	0·50
...	2·2	14·7	14·7	0·50	

Discussions—Since the dynamic friction between the belt and the flywheel fluctuates slightly, the pointers of the balances as well as that of speedometer vibrate about some mean mark. So readings are to be taken by eye-estimation.

ORAL QUESTIONS

What is meant by the term Horse power of a Machine? How is the horse power related with the efficiency of a machine? If designed to run with an optimum load, would the horsepower change if the load is increased or decreased? If so, why?

APPENDIX

Use of Rider in a Balance

If the physical balance is very sensitive, an attempt to weigh a body by the method of oscillations proves very troublesome due to the following reasons :—

(i) When the beam oscillates, the damping of the oscillations is so small that the successive readings of pointer on the scale are very nearly the same. Modern balances are designed to have shorter beam and so oscillations are comparatively quicker. In the circumstances, it is difficult to *record the turning points* of the pointer accurately.

(ii) Weight boxes are provided with 10 milligrams or 5 milligrams as the lowest 'weights'. For sensitive balances change in resting points by placing an extra load of this weight may not be accurately determined.

(iii) The method of oscillations needs the determination of resting point at each step which involves calculations and so the process is lengthy.

To avoid these troubles, a 'rider' may be used more conveniently when weighing. The rider R is a small piece of thin wire generally of platinum and is of a definite mass bent in the form of a loop with two legs as shown in Fig 103. It can be mounted upon the balance beam with its legs on opposite sides and so is the name 'rider'. A balance, designed for the use of a rider, has got equidistant graduations on the beam. One mode of graduation consists in *each half* of the beam being subdivided into one hundred equal divisions, beginning from the centre of the beam as zero and ending

just above the stirrup at 100. The rider of this type of balance is generally of a mass of 10 milligrams. In another mode of graduation, the whole length of the beam is subdivided in 100 divisions, the fulcrum being at the 50th graduation. The rider used with a beam of this type has generally a mass of 5 milligrams. The mass of the rider to be used with a balance depends upon its sensitivity.

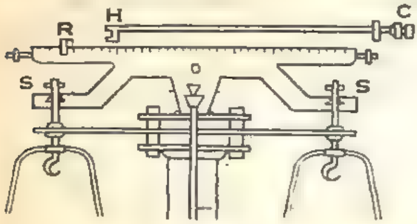


Fig. 103

To operate the rider, there is a rod having a curved hook H at its end and capable of being slided through a hole in the balance box. This rod is slided to the required region and by slightly turning it, the rider is raised up from any point of the beam by the hook and may be placed at any other point.

To use a rider with a balance when its beam is graduated having its zero mark at the centre, the rider is first placed at the zero position just above the fulcrum. At this position the rider is perfectly balanced on the beam. Then the beam is raised up and the oscillations of the pointer are examined. If unequal oscillations about the zero of the scale are observed, the nuts at the ends of the beam are suitably adjusted to get *equal oscillations* about the zero point. This is called the **zero adjustment** of the balance.

Next the body is placed on the left pan and by repeated trials suitable 'weights' from the weight box are placed to counterpoise the body as much as possible. Under this condition the point would oscillate on the scale but the oscillations would generally be *unequal* about zero. If larger oscillations are obtained *on the right*, the beam is lowered and the rider is shifted by the rod *to the right* on any graduated mark and again the oscillations are examined. If still unequal oscillations are found, then by repeated trials the rider is placed on such a graduation so that *equal oscillations about zero* is obtained. Care must be taken to lower down the beam before shifting the rider.

Suppose that the total mass of the 'weights' placed be M gms. and the rider is on the sth graduation on the right side of the beam for equal oscillations. Then if m be the mass of the rider in gram weight and total number of divisions on the right side of the beam be n, then the mass of the body is $\left(M + \frac{m}{n} s\right)$ gm. As an illustration, let the total mass of the weights on the pan be 8·28 gm., and the rider of mass ·01 gm. is placed on the 48th, division on the right side beam having 100 divisions on each half. Then the rider contributes $\frac{\cdot 01}{100} \times 48 = \cdot 0048$ gm. Then the mass of the body is 8·2848 gms.

If, on the other hand, with the body and suitable weights on the pans, the oscillation are greater on the left, the rider is to be

shifted on the left side to get the exact balance. In that case the mass of the body is $\left(M - \frac{m}{n} s\right)$ gms.

When the balance has a beam scale beginning from *extreme left*, the rider is to be placed on zero at the left end of the beam. Then with empty pans, equal oscillations are to be made by adjusting nuts. Then the body is placed on the left pan and suitable 'weights' on the right till oscillations are obtained on the scale but oscillations *are larger to the right*. This condition must always be attained. Then by repeated trials the rider must be placed on a graduation to get equal oscillations. Let P be the total mass of the 'weights' in gram weight and m be the mass of the rider which is placed on the graduation on a scale having n number of divisions, then the actual mass of the body is $\left(P + \frac{m}{n} \times s\right)$ gms.

Theory of the Method—First consider the balance beam having zero mark at the centre. If the rider of mass m gm. be placed at the centre, the moment of the mass of the rider about the fulcrum is nothing. If again the rider is placed at the last graduation on any end of the beam, the moment of the mass of the rider is $m \times l$ gm. cm. where l represents the half length of the beam. Let one small division of the balance beam be of length s cm.; and n be the number of divisions in one half of the beam. Then $s \times n = l$ Similarly, if the rider be on rth graduation, then the moment of the rider mass about fulcrum is $m \times s \times r$ gm. cm.

Now consider that with a body of mass P gm. on the left pan and a total mass of the 'weights' on the right pan together the rider on the rth graduation on the right the beam is in equilibrium. Then about the fulcrum,

Moment of the mass of the body
= Moment of the mass M of the weights
+ Moment of the mass of the rider.

$$\therefore \quad P \times l = M \times l + msr = M \times l + mr\frac{l}{n}$$

$$\text{whence} \quad P = M + m\frac{r}{n} \qquad \ldots \quad \text{(i)}$$

From a similar consideration, it can be proved that if the rider be on the rth graduation to the left, then other considerations being similar,

$$P + m\frac{r}{n} = M \quad \text{or,} \quad P = M - m\frac{r}{n} \qquad \ldots \quad \text{(ii)}$$

Applying the law of moments to the balance having its beam graduated from the extreme left, it can be shown that in all cases

$$P = M + m\frac{r}{n} \qquad \ldots \quad \text{(iii)}$$

where n represents the total number of divisions on the beam and the rider is on rth graduation from the extreme left.

CHAPTER IV

EXPERIMENTS ON HEAT

Heat

Heat is defined as the physical agency which produces the sensation of hotness or coldness. The fact that different forms of energy for example, mechanical, electrical, magnetic or luminous, can be converted into heat, proves that heat is another form of energy. The kinetic energy of vibrating atoms and molecules within material bodies manifests itself as heat energy while in free space the propagation of heat takes place in the form of electro-magnetic waves.

There are various sources from which heat may be derived. Of these the sun is the principal source. Heat is evolved in many chemical reactions and mechanical processes such as friction, collision or compression. Electric current flowing through a metal wire generates heat as in electric lamps and heaters. In a few cases heat is produced when a substance undergoes a change of physical state.

Effects of Heat

When heat is applied to a substance, one or other of the following effects may be produced—

(a) *Change of Temperature.*—When heat is applied to a body, it becomes heated. We then say that the body rises in temperature in relation to its surroundings. It is then in a condition to impart heat to other bodies colder than it. Conversely, when heat is taken out of a body, it grows colder than its surroundings and so it is in a condition to receive heat from bodies hotter than it.

(b) *Change of Volume.*—Along with its rise of temperature, it is generally found that a body expands while heated. Conversely, along with a fall of temperature, a body is found to contract in volume.

(c) *Change of State.*—When a solid body is continuously heated, its temperature rises till it begins to melt. Here the temperature is arrested during the period of melting, although heat is being absorbed by the body. So heat is required for the melting of the substance. Again when a liquid is continuously heated its temperature is raised to the boiling point and the liquid gets vaporised. The heat applied is utilised in vaporising the liquid without changing the boiling point temperature. All these are changes from one to the other condition due to the application of heat.

(d) *Change of Physical Properties.*—Properties like elasticity of solids, surface tension, solubility, heat and electrical conductivities, thermo-electric power etc. are affected by a change of temperature.

Temperature :

Temperature is defined as the thermal condition of a body which determines whether a body would communicate heat to or receive

heat from another body if put into thermal contact with each other. If heat passes from one body A to another body B when put into contact then A is said to have a higher temperature than B. In brief, the hotter is a body, the higher is its temperature; while the colder is the body, the lower is its temperature.

Thermometer :

A thermometer is an instrument which measures and compares temperatures of different substances. In constructing a thermometer use is made of some principal property of a substance, which changes continuously with the application of heat. The change in volume of mercury or alcohol is the most common property utilised in ordinary thermometers. But very sensitive thermometers are of electric resistance and thermoelectric types.

Fig. 104

Mercury-in-glass Thermometer—A mercury thermometer consists of a glass tube having a uniform capillary bore (Fig. 104). The capillary tube is provided with a bulb at one end and is sealed at the other end. The bulb and a part of the stem are filled with pure and dry mercury. The space within the capillary bore above mercury contains a little mercury vapour and nothing else. When there is a change of temperature of the bulb, the volume of the contained murcury changes, as shown by a rise or fall of mercury level within the stem. The stem is graduated in accordance with some standard scale so that each division represents an equal change of temperature. There are three scales of temperature—(i) *Centigrade* or *Celsius* (ii) *Fahrenheit*, and (iii) *Reaumur*. The lower fixed point of each scale is the temperature at which pure ice melts at normal pressure and the upper fixed point is the temperature at which water boils at a pressure of 76 cm. The following table furnishes a comparion of different scales—

Scale	Ice point	Steam point	Number of divisions between fixed points
Centigrade (C)	0°	100°	100
Fahrenheit (F)	32°	212°	180
Reaumur (R)	0°	80°	80

Mercury boils at 357°C and freezes at—39°C under standard atmospheric pressure of 76 cm. So it can be used as a thermometric substance for a fairly long range of temperature within these limits. It is a good conductor of heat and has a low thermal capacity. The expansibility of mercury with temperature is uniform and the vapour pressure of mercury is low for ordinary range of temperature. For

all these considerations mercury is considered as the best liquid for the thermometric substance. But when a temperature lower than —30°C is to be measured, an alcohol thermometer is used, since alcohol can remain in a liquid state even at a temperature of —130°C. (For a more detailed study of thermometers vide Basu & Chatterjee's Intermediate Physics, Heat, Chap. 1).

Date—

EXPERIMENT 53

To Determine the Fixed Points of a Thermometer

(a) *Freezing Point*

Theory—The lower fixed point of a thermometer or more commonly known as the ice point is the temperature at which *pure* ice melts under ordinary atmospheric pressure. This temperature is found to be sensibly constant being very little affected by a moderate change of *atmospheric pressure*. This temperature is 0°C according to the Centigrade scale or 32°F according to the Fahrenheit scale.

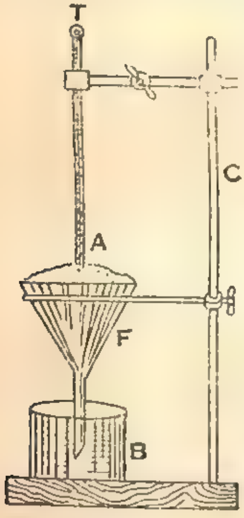


Fig. 105

Apparatus—A thermometer (Centigrade or Fahrenheit), a glass funnel, a stand with a ring, a lump of ice and a clamp to hold the termometer.

Procedure—Wash the funnel F and place it on the ring just above the glass beaker B (Fig. 105). Take a lump of ice, wash it in cold water, wrap it up with a piece of towel and afterwards pound it to small pieces. Fill the funnel completely with pounded ice. Any water formed by melting ice is collected in the beaker placed underneath.

Make a small hole in the ice near the middle of the funnel by means of a thin glass rod.* Put the bulb of the thermometer T into the hole so that the freezing point mark on the thermometer stem is a little above the surface A of the ice and start a stop-watch. Clamp the thermometer vertically to the stand C. As ice gradually melts hole containing the bulb gradually gets bigger. Pack ice occasionally round the bulb of the thermometer to ensure a good contact with the bulb.

As soon as the bulb is placed in ice, the level of mercury within the stem begins to fall. Record the temperatures at an interval of one minute by observing *along the level of* the mercury surface. This

*The thermometer must not be used to bore the hole within ice, because the bulb of the thermometer which is made of thin glass may crack in such a case.

avoids parallax error. Apply eye-estimation whenever mercury level stands between any two successive graduations. Ultimately a temperature is attained which does not appear to change with time. Continue taking readings for 5 to 10 minutes at the stationary region to be sure of the constancy of temperature. This constant temperature gives the lower fixed point.

Discussion—Care must be taken so that during the course of observation the bulb of the thermometer is always in direct contact with ice, as otherwise the hole containing the bulb grows bigger and a thin film of air is formed between the ice and the bulb. The air being a bad conductor of heat does not allow the temperature of the bulb to attain the temperature of the melting ice. This is done by occasionally packing ice round the bulb. It is convenient to use a magnifying glass in order to read the mercury head of the thermometer.

Results

Time	Temperature	Apparent freezing point	True freezing point	Correction
min.	°C	°C	°C	°C
0	24·5			
1	5·0			
2	0·5			
3	0·1			
4	0·1 (Stationary)	0·1	0°C	−0·1
5	0·1			
...	...			
...	...			
10	0·1			

The correct reading for the freezing point should be 0°C or 32°F. But generally for ordinary thermometers, the observed reading is a little above or below the correct reading. Hence a correction is necessary which is the true reading minus the observed reading.

Boiling Point

Theory—The upper fixed point or the boiling point is that temperature as recorded by thermometer when its bulb is placed in steam given off by boiling water under an atmospheric pressure of 76 cm. of mercury. This temperature is 100°C according to the Centigrade scale or 212°F according to the Fahrenheit scale. As the temperature of boiling water, even at a pressure of 76 cm. of mercury slightly changes due to dissolved impurities and contamination of the boiler, the bulb of the thermometer is not put into the boiling water but is kept up in steam whose temperature depends upon the pressure only.

Apparatus—A hypsometer, a thermometer, a barometer and some quantity of pure water.

A hypsometer consists of a metallic vessel P, called the boiler provided with two vertical co-axial cylindrical tubes J called jackets (shown in section in Fig. 106). The inner tube opens into the annular space between the jackets. An exit pipe O is fitted on to the outer jacket. There is another opening at the lower part to which a manometer M to read the inner pressure may be fitted. A stopper C is provided at the top having a vertical hole through which a thermometer can be inserted. A hypsometer as it looks externally is shown in Fig. 107.

Procedure—At the start open the stopper of the hypsometer and pour water to about half the volume of the boiler.*

Fig. 106

Fig. 107

Insert a thermometer through the hole of the stopper to such a length that its bulb remains above the water level. If necessary, wrap up the thermometer with a piece of paper before insertion to make it tightly fitting in the hole(‡). Fit the stopper on to the top. Place the hypsometer upon a tripod stand and apply heat with a Bunsen flame till water begins to boil. Record the readings of the thermometer at intervals of one or two minutes. It is found that the mercury head rises continuously and then becomes stationary near the top of the stem. Take the atmospheric pressure with a barometer. The temperature at which the mercury head becomes stationary gives the boiling point corresponding to the observed pressure. Read the mercury level avoiding parallax and applying eye-estimation. Calculate the true boiling point at this pressure from a theoretical formula and find the necessary correction which is the true steam point minus the observed steam point.

---

*The height of water within the hypsometer may be ascertained by introducing through the top a clean rod and examining what length of the rod has been moistened.

§A moderately tight fitting of the thermometer ensures two purposes. Firstly, the thermometer may not slip down the 100th mark, and secondly steam may not escape through the space between thermometer and the cork to fog the graduations.

Thermometer Readings—

Time	Temperature		Observed Steam point	True Steam point	Correction
min.	°C		°C	°C	°C
0	24·5				
2	80 5				
4	98 0				
6	98 9				
8	99 9	Stationary			
10	99 9	Stationary	99 9	99·96	99·96 – 99·9 =0·06
...		Stationary			
16	99·9	Stationary			
..	..				
20	99·9				

No of Reading	Barometer Reading =P cm.	Mean Reading cm.	Normal pressure cm.	Correction (76—P) × ·37 °C	True Steam point °C
1.	75 960				
2.	...	75·960	76 0	0 04	100 – 04 =99·96
3.	75·960				

Discussions—The bulb of the thermometer should remain a little above the water level within the hypsometer since the temperature of the steam at a given pressure is constant while the temperature of boiling water might vary due to various reasons. The water should not be allowed to boil too vigorously within the hypsometer, as otherwise the steam pressure within it would be sufficiently greater than the atmospheric pressure and consequently the boiling point of water would be raised affecting the result.

Date— EXPERIMENT 54

To Determine the Upper Fixed Point of a Thermometer and the Correction due to exposed Column

Theory—The upper fixed point of a thermometer is defined as the steady temperature of the issuing steam from water boiling under normal atmospheric pressure of 76 cm. of mercury. This temperature on the centigrade scale is taken as 100 which is indicated by an accurately calibrated thermometer when the bulb and whole of the stem is immersed in steam. For the stem to be partially out of steam, the thermometer reads a little less than 100 in proportion to the length of exposed stem.

Apparatus—A hypsometer, a barometer, a thermometer and some quantity of water.

Procedure—Fill the boiler about half with water and insert the stem of the centigrade thermometer into the hysometer through the hole in the stopper so that the whole of the stem upto nearly 100°

is enclosed within it. Heat the boiler till steam is given off continuously. Note the reading of the thermometer with a good magnifying glass when the mercury head becomes steady.

Raise the stem of the thermometer until graduations between 90° and 100° are exposed. Wait a few minutes until the mercury head again becomes steady and take the reading of the thermometer with the magnifier. Repeat observations with the stem exposed from 80 upwards, from 70 upwards and so on, till the whole stem from 0° to 100° becomes exposed. It is found that the readings of the thermometer for the boiling point continuously record a slight fall as the exposed column is increased.

Draw a graph with the length of exposed column as ordinate and the corresponding boiling point as abscissa, which is found to be a straight line.

Results—

No. of Readings	Range °C	Stem exposed	Thermometer reading t_1 °C	Correction in °C = σ
1.	100 – 90	...	99·9	0
2.	...	...	...	...
...	...	...	...	...
10.	10 – 0	...	99·7	0·2

Discussions—The difference in the levels of mercury within the stem as the exposed column is changed is due to the fact that mercury within the stem and the bulb is not at the same temperature causing a change in the volume of mercury.

Expansion of Solids

When a solid is heated, it expands in all directions, although the expansion is usually very small. The increase in length of a body is called the linear expansion. The increase in area is called *superficial expansion* and that in volume the *cubical expansion*.

The increase in length of a body is found to be proportional to the original length of the body, to the rise of temperature and it depends upon the material of the solid.

The *coefficient of linear expansion* of a solid is defined to be the increase in length per unit length of the material for a rise of temperature of 1°C from 0°C. This co-efficient in case of a solid is found to be fairly constant for a moderate range of temperature. If l_t and l_o represent the lengths of the rod at t°C and 0°C, then by definition,

$$\text{Co-efficient of linear expansion} = \alpha = \frac{l_t - l_o}{l_o t}$$

$$\text{or,} \quad l_t = l_o\,(1 + \alpha t)$$

Again, if l_2 and l_1 represent the lengths of the rod at t_2°C and t_1°C respectively,

Then $l_2 = l_0(1+\alpha t_2)$ and $l_1 = l_0(1+\alpha t_1)$.

So $\dfrac{l_2}{l_1} = \dfrac{1+\alpha t_2}{1+\alpha t_1} = (1+\alpha t_2)(1+\alpha t_1)^{-1}$

Now α for solids is found to be of the order of 10^{-5} per °C. Hence α^2 is of the order of 10^{-10} per °C. So higher powers of α may be neglected in the expansion of $(1+\alpha t_1)^{-1}$

$$\therefore \quad \frac{l_2}{l_1} = (1+\alpha t_2)(1-\alpha t_1) = 1+\alpha(t_2-t_1)$$

$$\text{Whence} \quad \alpha = \frac{l_2-l_1}{l_1(t_2-t_1)} = \frac{\text{increase in length}}{\text{original length} \times \text{rise of temp.}} \quad \ldots \quad \text{(i)}$$

Liquids have greater expansibility than solids; gases have still greater expansibility.

Date—

EXPERIMENT 55

To Determine the Co-efficient of Linear Expansion of a Rod by Pullinger's Apparatus

Theory—If l_1 be the length of a rod at the room temperature t_1°C, and l_2 be its length at some higher temperature t_2°C, then the coefficient of linear expansion α of the rod is given by the relation $\alpha = \dfrac{l_2-l_1}{l_1(t_2-t_1)}$.

Apparatus—Pullinger's apparatus, spherometer, a metre scale, two thermometers, a boiler and some rubber tubing.

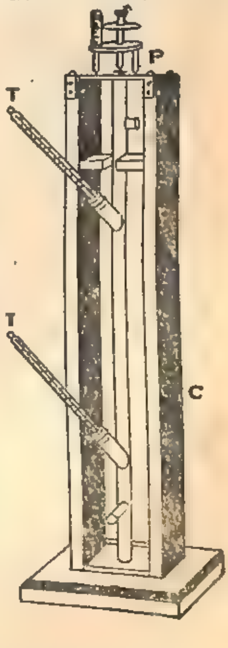


Fig. 108

The apparatus consists of a metal cylinder R closed at two ends and held vertically in an wooden frame C (Fig. 108). In some other form, the rod under investigation is enclosed in a steam jacket. The pipe is provided with two openings, one near the top and the other near the bottom, which serve as the inlet and outlet for steam. There are two other inclined side tubes through which two thermometers can be inserted to determine the temperature of the pipe. The stand is provided with a glass plate P at its top. The top of the pipe projects a little through a hole cut at the centre of the plate. A spherometer can be placed on the glass plate with its central leg touching the pipe.

Procedure—Measure the length of the pipe with a metre scale at the room temperature correct to the nearest millimetre. Fit up the pipe vertically on its stand and place the usual glass plate at the top. Put a boiler containing water upon a tripod stand and connect it by a rubber tubing to the upper spout of the pipe. Connect one end of another piece of rubber tubing to the lower exit spout and dip the other end into a vessel containing

water. Fit up two thermometers into two other openings as shown in the diagram. Take the readings of the thermometers; their mean value gives the temperature of the pipe when cold.

Observe the total number of divisions on the circular head of the spherometer supplied Get the value of the smallest division of the vertical scale attached to the spherometer stand. Give the circular head a *complete* turn and note through what distance the edge of the circular disc moves. This distance is called the pitch of the spherometer screw. Then the pitch divided by the number of divisions on the circular heads gives the *least count* of the spherometer. (For details vide Expt. 6). Place the spherometer upon the glass plate such that its outer legs rest upon the plate. Rotate the spherometer head so that the middle leg just touches the upper end of the rod and take the reading of the spherometer in the position. The position of contact should be ensured by the slight spinning motion of spherometer. Record three such readings *for the same point of contact* and find the mean value.

Now raise up the middle screw of the spherometer sufficiently and heat the boiler over a Bunsen flame. The temperatures as recorded by the thermometers are seen to rise continuously. When the temperatures, as recorded by the thermometres, become stationary for at least 10 minutes, screw down the middle leg of the spherometer again so as to touch the upper surface of the rod at the same point and take the reading of the spherometer. Record three such readings and find the mean value. Take the readings of the thermometers; their mean value gives the temperature of the pipe while hot. This should be very near 100°C.

Results—The mean length of the rod at the room temperature as measured with a metre scale = 100·2 cm. (say)

(Three readings for the length are to be taken)

Room temperature as recorded by

the upper thermometer = 22·5°C

" " " lower " = 22°C

∴ mean room temperature = 22·25°C

The pitch of the spherometer screw = 0·5 mm.

The number of divisions on the circular scale = 100

∴ the least count of the spherometer = 0·005 mm.

To record the readings of the spherometer at the room temperature and those the higher temperature direction as given in Expt. 6 should be followed.

The mean initial reading of the spherometer = 2·225 mm.

" " final " " " = 3·665 mm.

∴ The elongation of the rod = 1·440 mm. = ·144 cm.

Higher temperature as recorded

by the upper thermometer = 98·5°C

" " lower " = 97·5°C

mean higher temperature = 98°C

$$\therefore \quad \alpha = \frac{\cdot 144}{100\cdot 2(98 - 22\cdot 25)} = 1\cdot 9 \times 10^{-5} \text{ per °C.}$$

Discussions—When recording a set of readings with a spherometer care should be taken to see that the spherometer does not move bodily so as to alter the point of contact with the rod because the upper surface of the rod may not be exactly a horizontal plane and so an error would be introduced in measuring the elongation if the point of contact shifts. When using a metal pipe instead of a rod, arrangements should be done to cover it with felt or cotton in order to minimise the loss of heat by convection and radiation as otherwise the outer surface of the pipe would not be at the same temperature as its inside.

ORAL QUESTIONS

What is meant by coefficient of linear expansion? In measuring the coefficient why you are not considering the length of the rod at zero degree centigrade? Will its value change if the length of the rod be measured in feet or centimetres? What difference in value of the coefficient takes place if a Fahrenheit scale is used instead of a Centigrade scale? Would there be any difference in the value of the coefficient if instead of a solid rod a hollow pipe of the same material is used? What would be the trouble if the lower pipe is used as the inlet for the steam? Does it make any difference in the accuracy of measurement when you measure the length of the rod with an ordinary metre scale while you measure its expansion with a spherometer? Does this co-efficient change with different materials?

Date—

EXPERIMENT 56

To Measure the co-efficient of Linear Expansion by Vernier Microscope

Theory—If l_1 and l_2 be the lengths of a rod at temperatures t_1°C and t_2°C respectively, then the mean coefficient of the expansion is given by the relation,

$$\alpha = \frac{l_2 - l_1}{l_1(t_2 - t_1)} \text{ per } ^\circ\text{C}.$$

Apparatus—A metal pipe with heating arrangements, a metre scale and a beam compass, a pair of vernier microscope, boiler and connecting pipes, two thermometers.

The apparatus consists of a metal pipe, AB open at both ends and having an outlet pipe at the middle (Fig. 109). It is wrapped up with some nonconducting substance such as felt, cotton etc. to preserve the heat supplied to it as much as possible. Two scratch marks are made at the ends of the pipe. There are two vernier microscopes M_1 and M_2 which slide over a horizontal scale fitted to a suitable stand.

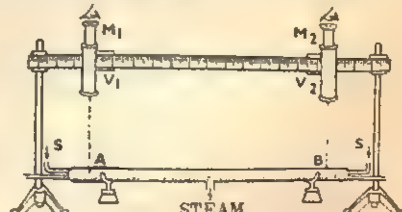


Fig. 109

Procedure—Measure the length between two scratch marks at the ends of the pipe with a beam compass or a metre scale correct to the nearest millimetre. If scratch marks are not there, knot two pieces of thread near at ends and

find the distance between the knots with the beam compass correct to the nearest millimetre.

Fix up two thermometers within the holes on the pipe. If the thermometers fit very slack, steam would escape through the intervening space and may fog thermometer graduations. In such a case wrap up the thermometers with pieces of paper and refit them into the holes. Connect two rubber tubes to the ends of the pipe from the boiler and another tube to the exit port for steam. Immerse the other end of this latter tube preferably in water in a pot.

Get the value of the smallest division of the main scale over which the microscope slides. Bring vernier zero line in concidence with any main scale graduation and count the number of vernier divisions which are equivalent to the number of main scale divisions. Hence find the vernier constants of both the microscopes (vide Exp. 7) Focus the cross-hairs of the microscopes by adjusting eye-piece alone Now adjust the positions of the microscopes such that the scratch marks are below the object glass of the microscopes and then focus the scratch marks by operating the focussing screws. When the scratch marks are distinctly in focus, slight lateral movements of the microscope are necessary to bring the scratch mark exactly in coincidence with the cross-hair. Now take the readings of the verniers and the readings of the thermometer. Then heat the boiler and pass steam into the pipe from the boiler. The thermometers record a rising temperature and when the *temperatures become steady*, read both the termometers Focus the microscopes again on the scratches and read verniers. The difference of vernier readings at each end of the pipe gives the elongation at that end. The total elongation is evidently the sum of the elongations of the two ends.

Results—

The length of the pipe between two scratch marks
=(i)......cm. (ii)......cm. (iii)......cm.
Hence mean length=......cm.
Temperature of the pipe, when cold=......°C
Steady high temperature=(i)......°C (ii)......°C
Mean high temperature=......°C
Least count of the Vernier=......cm.

	Original Reading			Final Reading			Difference cm.
	M.S.	V.S.	Total cm.	M.S.	V.S.	Total cm.	
Vernier 1	...	...	...	...	...	...	
Vernier 2	...	...	...	...	...	...	

Hence total elongation=...+...cm.

$\therefore \quad \alpha=$

Discussions – The accuracy of results obtained depends upon the accuracy with which the expansion is measured. The rubber tubes and thermometers are to be fitted with the metal pipe before any reading is taken. Any mechanical adjustment done later would alter the reading of the microscopes and so the pipe must not be touched after starting to take reading. It may sometimes happen that one of the thermometers does not indicate a rise of temperature. This due to the clogging of water within the rubber tubing of that end. The clogging must be cleaned up for a successful experiment. A vernier microscope may read accurately upto one-thousandth of a centimetre.

Oral Questions

In addition to the questions of previous experiment: Why do you call your result the mean coefficient of expansion? If the tube of your experiment be replaced by a solid rod of the same material, would the value of coefficient of expansion change? In the spherometer method you have to measure the elongation of one end while in the vernier microscope method you measure elongation of both ends; do you think that their values for the same material would be equal? Of the Pullinger's appratus and vernier microsocpe method, which one is, according to your opinion, more accurate and why?

Rotation of a Mirror

It is known from the principle of reflection of light in Geometrical Optics that if a mirror rotates by an angle, the reflected beam of light from this mirror rotates by double the angle. This device is utilised in measuring a small increase of length of a rod.

Date –

Experiment 57

To Measure the co-efficient of Linear Expansion by Optical Lever Arrangement

Theory – If e be the expansion of a rod of length l for a rise of

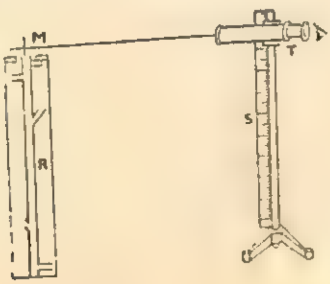


Fig. 110

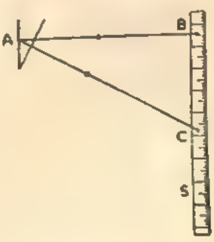


Fig. 111

temperature $t_2 - t_1$, then the coefficient of linear expansion α of the material of the rod is given by.

$$\alpha = \frac{e}{l(t_2 - t_1)}$$

If this expansion is measured by an optical lever of arm length s producing a spot shift of x on a scale placed at a distance of D from the lever, then,

$$e = \frac{sx}{2D}$$

Combining the two expressions, we have

$$\alpha = \frac{sx}{2lD(t_2 - t_1)}$$

Apparatus—The specimen rod, boiler and heating arrangements, lamp, scale and telescope, optical lever, metre scale, two thermometers.

Procedure—Place the scale S attached to the telescope and the specimen rod R vertical. Place the rod with its holder at a fair distance (3 to 4 metres) from the telescope and adjust the height of the rod so that its top is approximately at a level occupying the middle region of the scale (Fig. 110) Place a lamp at the middle part of the scale facing the specimen rod Insert thermometers within the holes of rod and note the initial temperatures.

Fit up the boiler and make necessary arrangement for heating the rod but *do not start heating now*. Place the optical lever M with the pivot at the top of the rod and fulcrum at a fixed level of the cover. Look through the mirror of the lever and get the reflected image of the lamp. Rotate the lever through a vertical axis, if necessary, so that the image of the lamp is along the line joining the telescope and the mirror, and at the same time rotate the mirror along horizontal axis so that image of the lamp appears to be in a horizontal plane. Stand near the telescope and try to get the image of the lamp through the naked eye. Finally adjust the telescope to get a *clear* image of the lamp on the cross wires. Remove the lamp a little so that scale is well illuminated. The scale is now clearly visible in the field of view of the telescope. Get the part B of the scale in the field of view (Fig. 111).

Take the reading of the scale on the crosswires of the telescope. Let it be x_1. Now light up the burner without *disturbing the position of the lever* etc. When steam passes through and heats the rod, observe through the telescope the changes in readings. When the reading again becomes stationary, the thermometers record a steady higher temperature; take the reading of the scale. It would be some region on the scale. Let it be x_2. Let $x_2 \sim x_1 = x$.

Then measure with a tape or otherwise the horizontal distance D from the scale to the mirror of the optical lever to the nearest centimetre. Press the optical lever on a piece of white paper, when three dots would be imprinted on it. Now join the two dots under the fulcrum with a fine line and draw a pependicular from the third dot on this line. Measure the length of this perpendicular with a diagonal scale or a vernier microscope. Let it be d.

Results—

Length of the rod at the room temp =(i).........(ii) ....cm.
Hence mean length of the rod l = ...cm.
Initial temp of the rod = (i)......°C (ii)......°C
Hence mean initial temp t = ...°C
Initial reading on the scale = ...cm.
Final reading on the scale = ...cm.
Hence x = ...cm.
Distance from the scale to the mirror = (i)—...cm. (ii)...cm.
Hence mean distance D = ...cm.
Final temp. of the rod = (i)......°C (ii)......°C
Hence mean final temp. = t_2 = ...°C.
Length of the arm of the lever = (i)......cm. (ii)......cm.
Hence mean length d = ...cm.
Hence α = ...per °C.

Discussion—The accuracy with which the expansion may be measured in this experiment depends upon the distance of the telescope from the mirror. Hence by increasing this distance the sensitiveness of the apparatus may be increased to any desired extent. This arrangement is a convenient method of measuring linear expansion accurately.

ORAL QUESTIONS

In addition to the questions of the two previous experiments: What is the advantage of using the optical lever attachment? What does it really measure.—a distance or an angle? Suppose you are supplied with two optical levers,—one with a larger arm: which is expected to give a more accurate result and why? A spherometer or a vernier microscope has a fixed least count, while an optical lever has a variable least count: explain the statement. What is the linear magnification of an optical lever?

Expansion of Liquids

Liquids have, in general, larger expansibility than solids for a given rise in temperature. But as liquids have no definite shape of their own, always taking the shape of the containing vessel, they possess *cubical* or *volume expansion* only. Different liquids have different expansibilities.

Real and Apparent Expansions—The expansion of a liquid due to a rise in temperature is always accompanied with the expansion of the containing vessel. If the expansion of the vessel is not taken into consideration, then the observed expansion of the liquid is called the apparent expansion; whereas the expansion of the liquid considering the expansion of the containing vessel is called the real expansion. Hence

Real Expansion = Apparent Expansion + Expansion of the vessel for a given rise of temperature.

Co-efficients of Real and Apparent Expansions—The co-efficient of real or absolute expansion of a liquid is given by,

$$\gamma = \frac{\text{real expansion}}{\text{volume at } 0°\text{C} \times \text{rise of temperture}}$$

The coefficient of apparent expansion of a liquid is given by,

$$\gamma' = \frac{\text{apparent expansion}}{\text{volume at } 0^\circ\text{C} \times \text{rise of temperature}}$$

If V_0 be the volume of a liquid within a vessel at 0°C and if the vessel is heated to t°C, then according to definition the real expansion of the liquid $= V_0 \gamma t$, the apparent expansion of the liquid $= V_0 \gamma' t$ and the expansion of that part of the volume of the vessel containing the liquid $= V_0 g t$, if g denotes the co-efficient of cubical expansion of the material of the vessel.

Thus, $V_0 \gamma t = V_0 \gamma' t + V_0 g t$

whence, $\gamma = \gamma' + g$

Date—

EXPERIMENT 58

To Measure the Co-efficient of Apparent Expansion of a Liquid by Weight Thermometer Method

Theory—If the mass of a liquid filling the weight thermometer at some lower temperature t_1°C be W_1 and mass of the same liquid filling the same bulb at some higher temperature t_2°C be W_2, then

$$\gamma' = \frac{W_1 - W_2}{W_2(t_2 - t_1)}$$

where γ' = coefficient of apparent expansion of the liquid.

Apparatus—A weight thermometer bulb and weight box, water bath, thermometer and heating arrangements, a quantity of glycerine, hot air blower.

A weight thermometer is a glass bulb with its neck narrowed down and drawn to one side. Types of bulbs are shown in (Figs. 112 & 113) The technique of bulb blowing is explained in the Appendix after Heat Experiments.

Procedure—As the bulb supplied or made in the laboratory is blown from clean glass tube, a preliminary cleaning is not necessary.

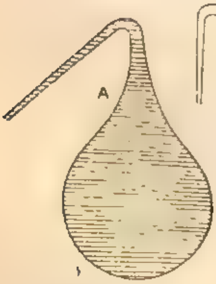


Fig. 112

Fig. 113

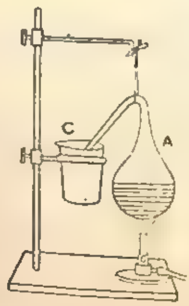


Fig. 114

Weigh the bulb in a balance preferably by the method of oscillations. Take two or three such weights. These weights should not differ from each other by more than 10 mg.

Take a quantity of glycerine in a porcelain crucible. On a tripod stand take a glass beaker almost filled with water. Place the weight thermometer bulb in a wire net cage with its neck projecting outside and suspend

the cage in water so that the tip of the neck of the bulb dips under glycerine within a small beaker or crucible (Fig. 115) Now heat the beaker with a burner. Water gets heated and air within the bulb expands and escapes as bubbles through glycerine. When sufficiently hot, remove the burner and the glass beaker with water but do not disturb the bulb with its mouth dipped into glycerine. The bulb gets cooled gradually and sucks in some quantity of glycerine. When no more sucking takes place, place the beaker again on the tripod and heat from below. Some air would again escape from the bulb. Cool it again as described previously and some more glycerine would find its way into the bulb. In this way by alternate heating and cooling, fill the bulb completely with glycerine at the room temperature t_1°C. Weigh the bulb and the contained liquid. Take two or three separate weights by the method of oscillations. The mean of the weights so found gives the mass of the bulb and the liquid at a temperature of t_1°C.

Take a water bath and place it above a tripod stand with a Bunsen burner below it. Then suspend the bulb with a piece of thread in the water bath with its neck outside water. Clamp or suspend a thermometer so that its bulb dips well into the water bath. Now light up the burner and stir the bath slowly. The liquid from inside the bulb is found to fall by drops. Now at a higher temperature, say t_2°C, between 30° to 40°C above the room temperature, adjust the gas tap so as to minimise the flame to such an extent that the temperature of the water bath remains constant. This would happen when the heat supplied to the water bath by the flame is equal to the heat lost by the water bath due to radiation and conduction. Stir water slowly all the while. When the thermometer reading is constant for at least 10 minutes, the stationary temperature is attained.

Note the temperature which is, say t_2°C and remove the bulb carefully from the bath. Allow it to attain approximately at the room temperature. Then take two or three separate weights in a balance by the method of oscillations.

Results—

Mass of the empty bulb :
(i) ...gm. (ii) ...gm. (iii)......gm. Mean.......gm. (m_1)
Mass of the bulb and glycerine at the room temperature t_1°C.
(i) ...gm. (ii) .....gm. (iii)......gm. Mean......gm. (m_2)
Mass of the bulb and glycerine at the higher temperature t_2°C
(i).......gm. (ii)......gm. (iii)..... gm. Mean......gm. (m_3).

If weights are taken with the method of oscillations, the tabulation for the resting points with necessary calculations, as given on pp. 62 must be entered.

Then mass of the liquid filling the bulb completely at the room temperature $t_1°C = m_2 - m_1 = W_1$ gm.

Mass of the liquid filling the bulb at $t_2°C = (m_3 - m_1) = W_2$ gm.

$$\therefore \quad \eta' = \text{Coefficient of apparent expansion} = \frac{W_1 - W_2}{W_2(t_2 - t_1)} \text{ per } °C$$

Discussions—Since the determination of apparent expansion of a liquid by this method involves the measurement of a few masses, accurate weighing is necessary each time. Hence weighing by the method of oscillations should be adopted. When filling the bulb with a viscous liquid, it is very difficult to drive away air bubbles sticking inside the bulb. These air bubbles may be removed by alternate heating and cooling of the bulb during the period of filling the bulb with the liquid. When the water bath is heated continuously, the bulb does not take up the temperature of the bath spontaneously. Consequently the temperature of the water bath is to be maintained constant for about 5 to 10 minutes in order that the bulb and its contents may attain that temperature.

Date—

EXPERIMENT 59

To Measure the Co-efficient of Real Expansion of Mercury by Dulong and Petit's Method

Theory—If h_1 and h_2 are the vertical heights of the mercury columns at steady temperature t_1°C and t_2°C in the U-tube of the apparatus, its base being supposed horizontal, then the coefficient of real expansion γ of mercury is given by the expression,

$$\gamma = \frac{h_2 - h_1}{h_1 t_2 - h_2 t_1} \text{ per °C.}$$

Apparatus—Dulong and Petit's apparatus of a simple form, two centigrade thermometers, boiler and heating arrangements, tap water connection, and a cathetometer.

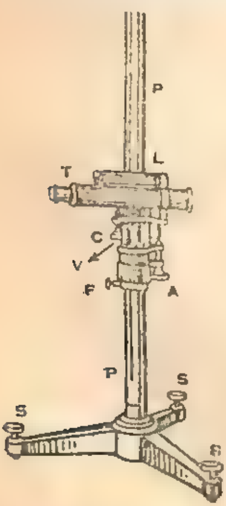


Fig. 115

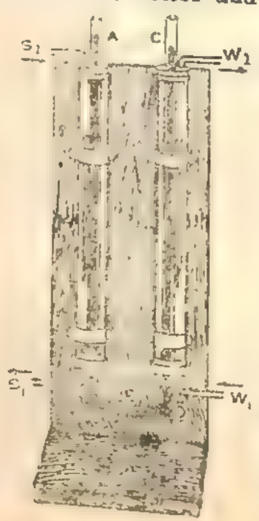


Fig. 116

A cathetometer is an instrument to accurately determine a length upto about a metre or so. It consists of a vertical pillar P graduated in centimetres (having millimetres as the least division) and fixed upon three levelling screws S (Fig. 115). A telescope T, provided with spirit level L can be slided over the pillar and fixed anywhere by turning the fixing screw F. There is also a levelling screw C attached to the carriage of the telescope. After fixing up the position of the telescope at any region, a small up and down motion of the telescope for finer adjustment may be made by the adjusting screw A. The telescope carries a vernier

scale V in order to be able to read its position very accurately and it is capable of rotation with the pillar as axis.

The expansion apparatus in a simple form consists of two L-shaped glass tubes AB and CD connected at the bottoms at the region E by rubber tubing, the combination forming a U-tube with the connected portion horizontal (Fig. 108). Each of the vertical limbs is jacketted by a wider glass tube (J_1J_2) with its end closed by stoppers. The jacket tubes are provided with outlets at the top and at the bottom.

Procedure—To set up the cathetometer vertical, place the telescope with its axis parallel to the line joining any two base levelling screws and call it the first position. To set the telescope parallel, it is more convenient to join two base screws by a straight line with a piece of chalk and then to turn the telescope so as to be parallel to this line. Now bring the bubble at the centre of the spirit level *about one-half the distance by the screw C and another half by any one or both the base screws.* Then rotate the telescope through 180°, when it again becomes parallel to the chalk mark and call it the second position of the telescope. Now bring the bubble of the spirit level at the centre by working *one or both the screws.* Bring the telescope back to its first position and level it again in that position. In a similar way repeat this procedure a number of times until the telescope has been levelled in these two positions. When this is done, place the telescope perpendicular to the chalk mark and bring the bubble at the centre by the third levelling screw The telescope has thus been levelled for all positions.

Examine the graduations on the pillar and find the vernier constant of the telescope. Adjust the position of the eyepiece of the telescope so that the cross-wire is distinctly focussed. Now turn the telescope towards any limb of the U-tube and focus the telescope to have a clear image of the limb. Lower the position of the telescope to bring into the field of view the horizontal (bottom) part of the U-tube and see whether the two bends of the tube are in focus and the middle part of each bend is at the junction of the crosswires. If not, make suitable adjustments to bring the bends at the same level.

Fix up two the thermometers within the jackets as close to the U-tubs as possible and connect one rubber tubing from the water tap to the *lower* inlet pipe of a jacket and another rubber tubing from the upper outlet pipe of the same jacket to the sink. Take a boiler filled with water and place it on a tripod over a burner. Connect the boiler with a rubber tube to the upper inlet pipe of this jacket and the other end of this tube should go into vessel containing water for deposition of steam when formed. The horizontal portion BD of the U-tube should be covered up by cotton or linen pieces soaked in water or a special device should be made for a permanent flow of water around BD.

Now pass cold water through one jacket and steam through the other and observe the readings of the thermometers. After some

time, the two thermometers would show *steady* temperatures,—one indicating temperature of circulating water and the other that of steam very near 100°C. When the *steady temperatures* have attained, read the thermometers and record them.

Focus the heads of mercury levels with the telescope at the cross wires and read the position of the verniers. Take alternately three sets of readings for each level. Then lower the telescope down and take the readings for the centre of both the bends of the U-tube. This may be done once. Again take the readings of the thermometers. Disconnect the rubber tubings of the jackets before you leave the working table.

Results—

Determination of Vernier Constant of the Cathetometer.

Smallest main scale division = ...mm.

...main scale = ...vernier scale.

∴ Vernier Constant = ...mm. = ...cm.

Temperatures at the begining of the Experiment.

Colder jacket = ...°C; hotter jacket = ...°C.

Telescope readings :—

No. of Observations	Readings for the top of cold column			Readings for the top of hot column		
	Main scale	Vernier Scale	Total	Main scale	Vernier Scale	Total
1.	...	...	...	...	...	...
2.	...	...	...	...	...	...
3.	...	...	...	...	...	...

Base Readings :

	Main Scale	Vernier Scale	Total	Mean cm.
Left Bend centre				
Right Bend centre				

Temperatures at the end of the Experiment—

Colder jacket = ...°C, hotter jacket = ...°C.

Mean temperature of the colder jacket = ...°C

Mean temperature of the hotter jacket = ...°C.

Mean reading for the top of colder column = ...cm. (*b*).

Mean reading for the top of hotter column = ...cm. (c)
Height of cold column $h_1 = b - a = ...$cm.
Height of hot column $h_2 = c - a = ...$cm.

$$\text{Mean coefficient of Expansion} = \frac{h_2 - h_1}{h_1 t_2 - h_2 t_1} = \text{...per } ^\circ\text{C.}$$

Discussions—When cathetometer is levelled, the upright carrying the telescope becomes vertical and all lengths determined become vertical heights. The readings of the telescope should not be taken unless the temperatures become stationary. In order that heat may not appreciably flow from the hotter to the colder end, arrangement for efficient cooling should be made at the horizontal part of the tube. This can be done by wrapping up the horizontal part of the tube by cotton soaked in cold water and spraying cold water intermittently upon it. There should not be any parallax error between the image and the cross-wire while taking any reading.

ORAL QUESTIONS

What are you measuring in this experiment,—apparent or real expansion? How is it that in spite of the expansion of the vessel you are getting here the absolute expansion of the liquid? Will your result alter if you take all measurements in inches? Would you get the same result if you are supplied with a Fahrenheit thermometer? Why do you cool the horizontal tube? What is parallax and what is the effect on the reading if the parallax error is not avoided? Why do you level the cathetometer? What is the defect if the cathetometer is not levelled?

Calorimetry

Heat is a form of energy and this energy can be measured. When a body is heated it gains heat; conversely when it is cooled it loses heat. The loss or gain of heat can be subtracted or added as any other scalar physical quantity. *Calorimetry* deals with the measurement of heat. The vessel used in such a measurement is called a calorimeter, which is a cylindrical vessel usually made of copper and provided with a stirrer of the same material.

Unit of Heat—The unit of heat in the C. G. S system is defined to be the amount of heat required to raise one gramme of pure water through 1°C. This is called the Gramme-Calorie or simply a calorie. The British Thermal Unit (B. Th U) is the quantity of heat requfred to raise one pound of water through 1°F.

Since 1 lb. = 453·6 gm. and $1^\circ\text{F} = \frac{5}{9}$ of 1°C.

1 B. Th. U = $(453\cdot6 \times \frac{5}{9})$ calories = 252 calories.

Specific Heat—Specific heat of a substance is the ratio of the quantity of heat required to raise a certain mass of the substance through any range of temperature to the quantity of heat required to raise an equal mass of water through the same range of temperature. If S be the specific heat of a substance,—

Then by definition,

$$S = \frac{\text{Heat required to raise } m \text{ gm of substance through } t^\circ\text{C}}{\text{Heat required to raise } m \text{ gm. of water through } t^\circ\text{C}}$$

$$= \frac{\text{Heat required to raise 1 gm. of the substance through } 1^\circ\text{C}}{\text{Heat required to raise 1 gm. of water through } 1^\circ\text{C}}$$

$= \dfrac{\text{Heat required to raise 1 gm. of the substance through } 1^\circ C}{1 \text{ calorie}}$

∴ Heat required to raise 1 gm. of the substance through $1^\circ C = S \times 1$ calorie.

Hence we can also state that the specific heat of a substance is equal to the number of units of heat required to raise 1 gm. of substance through 1°C. The specific heat *being a ratio has got no unit but is merely a number.*

Thermal Capacity—The thermal capacity of a body is the quantity of heat required to to raise the temperature of the body through 1°C. Thus, if m be the mass of the body in grammes and if s be the specific heat of the material of the body, the thermal capacity of the body is equal to $m \times s$ calories.

Water Equivalent—The water equivalent of a body is the number of grammes of water which will be raised through 1°C by the same amount of heat required to raise the temperature of the body through 1°C. Thus if m be the mass of the body and s be its specific heat, then the heat required to raise its temperature through 1°C is equal to ms calories. This quantity of heat will raise ms gm. of water through 1°C. Therefore, the water equivalent of the body is ms gm. Hence the thermal capacity of a body and its water equivalent are numerically equal but the thermal capacity is expressed in heat units while the water equivalent is expressed in grammes.

Principle of Measurement of Heat—If two bodies at different temperatures be mixed so as to be in thermal contact, there will be a sharing of heat between the bodies. The heat given out by the body at the higher temperature is taken up by the body at the lower temperature, until they attain a common final temperature. Assuming that no heat is received from or given to anybody outside the system or there is no chemical action in the process of mixing, heat lost by the hotter body is always equal to the heat gained by the colder body.

The experimental verification of this principle is carried out by taking a calorimeter of known mass containing a weighed quantity of a liquid at a known temperature. A known quantity of a substance either solid or liquid at some higher temperature is dropped into the calorimeter and is stirred thoroughly till the mixture attains a common temperature. Then heat gained is equated to heat lost. This is known as the method of mixture.

Modes of Transmission of Heat

There are three distinct processes by which heat energy may be transmitted from one place to another, namely (i) Conduction, (ii) Convection and (iii) Radiation.

Conduction—It is the process in which heat is transmitted from hotter to the colder parts of a body or from a hotter to a colder body in material contact without any transference of material

particles. Conduction of heat takes place always in solids and in particular case in liquids and gases.

Convection—It is the process in which heat is transferred from one point of a medium to another by the actual movement of meterial particles from a place of higher temperature to a place of lower temperature. Convection is not possible in solids but it mostly takes place in liquids and gases.

Radiation—It is the process in which heat can pass from one point to another without the intervention of any material medium. The vibration of atoms and molecules of a heated body are supposed to set up transverse wave motion in the free space, which travels out in all directions with a velocity of 186,000 miles per second carrying the heat energy from the source to the receiver. (For further details vide Basu & Chatterjee's Intermediate Physics, Part I, Heat Chap. VIII).

Loss of Heat by Radiation

It is found experimentally that the rate at which a body loses heat by radiation depends upon,

(i) the temperature of the body,

(*ii*) the temperature of the surrounding space where radiation takes place.

(*iii*) the nature and extent of its surface.

Hence if a given mass of a liquid, heated to a known temperature is kept in a certain vessel and allowed to cool in an enclosure at a lower temperature than that of the liquid, it will obey the above conditions. The rate of loss of the heat does not therefore depend on the nature of the liquid. Hence if allowed to cool in such a way that above conditions do exactly hold good in each case, different liquids will lose heat at the same rate. This principle is applied in the method of cooling and determination of specific heat.

Date—

EXPERIMENT 60

To Verify Newton's Law of Cooling

Theory—Newton's law of cooling states "the rate of cooling is proportional to the difference of temperature of the body and that of the surrounding." It means that when a heated body is left to itself, its temperature comes down continuously and the fall of temperature over a *small* interval varies as the *excess* of the temperature of the radiating surface above the temperature of the surrounding medium provided that this excess is not large (20° to 25°C).

Apparatus—A calorimeter and stirrer, a sensitive thermometer, a stop-watch, a beaker and heating arrangements.

Procedure—Take a glass beaker previously washed clean, fill it with water and heat it over a flame. Place an ordinary thermometer in it to record the rise of temperature.

Take a middle-sized calorimeter provided with a wire gauge stirrer, thoroughly clean and dry it and place it upon the table. Clamp a sensitive thermometer capable of measuring one-fifth or one-tenth of a degree centigrade so that its bulb dips into the calorimeter but allows the stirrer to be worked.

When the temperature of water in the beaker is about 30°C higher than the room temperature, take the beaker over the calorimeter and carefully pour hot water into the latter to a level that the bulb of the thermemeter is completely immersed. Slowly stir water within the calorimeter and start a stop-watch.

The temperature of water within the calorimeter slowly falls and when the temperature is about 25°C higher than the room temperature, note the temperature at an instant when the second hand of the watch passes by zero mark on the dial. Since then note the temperatures at intervals of a minute till the temperature comes down by 15° or 16°. All the while continuously stir water.

Results—

The Room Temperature: 31·4°C. (A typical record)

Time	Temperature	Time	Temperature	Time	Temperature
min.	°C	min.	°C	min.	°C
0	56	11	46·6	21	41·8
1	54·8	12	46·0	22	41·4
2	53·7	13	45·5	23	41·0
3	52·6	14	45·0	24	40·6
4	51·7	15	44·5	25	40·3
5	50·8	16	44·0	26	39·95
6	50·0	17	43·4	28	39·4
7	49·2	18	43·0	30	38·88
8	48·5	19	42·6	32	38·4
9	47·8	20	42·2	34	38·0
10	47·5				

Verification—Plot a graph with time in minutes as abscissa and temperature in degree centigrade as ordinate (Fig. 117).

The fall of temperature between 1st and 2nd minute

$$= 54{\cdot}8 - 53{\cdot}7 = 1{\cdot}1°C$$

The mean average temperature during the interval

$$(54{\cdot}8 + 53{\cdot}7)/2 = 54{\cdot}25°C$$

$\therefore$ The excess of temperature over that of the surroundings

$$= 54{\cdot}25 - 31{\cdot}4 = 22{\cdot}85°C$$

Hence cooling constant $= \dfrac{1{\cdot}1}{22{\cdot}85} = 0{\cdot}0048$ per minute.

In a similar way calculate the cooling constants over different ranges which are given below :—

No. of readings	Interval	Cooling	Mean Temperature	Mean Excess Temperature	Cooling Const.
	mins.	°C	°C	°C	
1.	1st and 2nd	1·1	54·25	22·85	·0048
2.	2nd and 3rd	1·1	53·15	22·75	·0048
3.	5th and 6th	0·8	50·4	19·0	·0042
4.	9th and 10th	0·65	47·5	16·1	·0040
5.	13th and 16th	0·55	45·25	13·8	·0040
6.	17th and 18th	0·5	43·25	11·85	·0042
7.	21st and 22nd	0·4	41·5	10·2	·0040
8.	25th and 26th	0·35	40·15	8·7	·0041
9.	29th and 30th	0·4	39·0	7·7	·0040
10.	35th and 36th	0·0	38·27	6·9	·0042

Discussions—The range of temperature of total cooling must not be large as in that case Newton's law of cooling would not hold accurately. This is evident from the cooling constants obtained from the experiment. The cooling constant for a range 53° to 56°C, is found to be ·0048, while the average value is ·0041. The thermometer used should be capable of measuring 0·1°C for a good accuracy of the experiment.

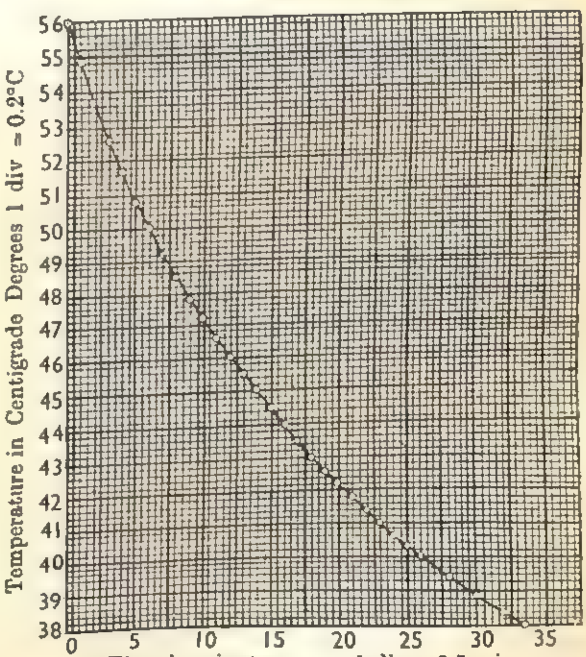


Fig. 117—Cooling curve

ORAL QUESTIONS

What is Newton's law of cooling and how far is the law correct ? Why does a hot body cool ? What are the factors governing cooling of a body ? A quantity of hot water initially at some higher temperature is allowed to cool in a copper vessel and another equal quantity of water at the same temperature in a brass vessel ; which one would show more rapid cooling and why ?

Radiation Correction

It follows from Newton's law of cooling that so long as a body is hotter than its surroundings, it would radiate heat continuously to its neighbours. The converse is also evident from the same law. If a body is cooler than its surroundings, it would gain heat by radiation from its neighbours.

In experiments with a calorimeter either a hot body is dropped in cold liquid or a cold body is dropped into a liquid at the room temperature and the resulting temperature is found with a thermometer. While the temperature of the mixture is rising above the room temperature, some heat is being radiated away from the exposed surfaces of the mixture and the calorimeter. Consequently the final temperature, as recorded by the thermometer, is less than that which should have been, had there been no radiation. Conversely, when the temperature of the mixture is falling below the room temperature, some heat is absorbed by the exposed surfaces of the calorimeter and the mixture, resulting in an *apparent* final temperature, which is higher than the true temperature. In either case the purpose of radiation correction is to determine such differences of temperatures.

Date— EXPERIMENT 61

To Determine the True Temperature of a Mixture by Radiation Correction

Theory—Whenever the temperature of a mixture is continuously rising above or falling from the surrounding temperature, there is some radiation of heat from or to the mixture The true temperature of the mixture is obtained by correcting for radiation loss or gain neglecting other effects which may be reduced to a minimum.

Apparatus—A calorimeter with a stirrer, a heater, a piece of solid (say, marble), some quantity of liquid (say, kerosene), a sensitive thermometer and a stop-watch.

Procedure—Suspend the piece of solid in a steam heater for sometime so as to be heated to a temperature much above the room temperature. Take some quantity of kerosene in the calorimeter so that the body may be completely immersed in it. Find the temperature of kerosene with a thermometer. Start the stop-watch. Now, drop the heated body into the liquid of the calorimeter without splashing the liquid and note the instant of immersion of the solid by the stop-watch. Swiftly, place the bulb of the thermometer within the liquid and stir the mixture *continuously* but slowly. Record the temperature of the mixture *every half minute* till a maximum temperature is reached. After this the temperature falls, but continue to take six to eight falling temperatures at intervals of half a minute or one minute. (See Time-Temperature record in Results). Then draw a graph with time as abscissa and temperature as ordinate which is shown as a continuous line in

Fig. 118. The average fall of temperature per half minute would be, according to Newton's law of cooling, proportional to the mean difference of temperatures of the mixture and the surroundings. The manner of calculating the average fall of temperature is shown in the results. Next draw another graph with the average fall of temperature as ordinate and mean temperature as abscissa, which would be a straight line (Fig. 118) From this graph find the amount of cooling per half minute at any mean temperature when the temperature of the mixture is rising. These values are shown in the third column of the tabulated data. Add up the total fall of temperature during the intervals from the instant of dropping of the solid to the maximum temperature attained or a little beyond it. Add this total fall to the apparent maximum temperature. It will be found that the corrected temperatures have become very nearly constant. Take the mean of a few fairly constant temperatures. This mean is the true maximum temperature.

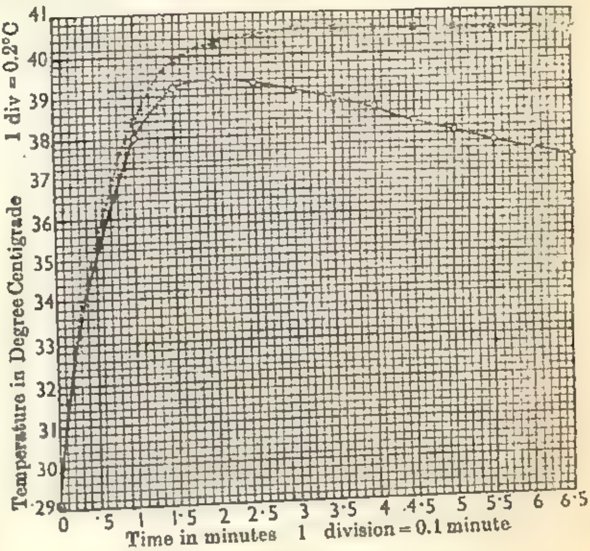


Fig. 118—Time-Temperature Curve

Results—Time-Temperature Record.

Time mins.	Observed Temperature °C	Mean Temp. °C	Cooling from graph °C	Total cooling °C	Corrected Temperature °C	Mean corrected Temperature °C
0	29·1	29·1	0	0	29·1	
0·5	35·0	32·0	·16	·16	35·16	
1	38·0	36·5	·24	·40	38·40	
1·5	39·2	38·6	·26	·66	39·16	
2	39·4 max.	39·3	·27	·93	40·33	
2·5	39·3	39·4	·27	1·20	40·5	
3	39·1	39·2	·26	1·46	40·56	
3·5	38·9	39·0	·26	1·72	40·6	
4	38·6	38·8	·25	1·97	fairly constant 40·57	
4·5	38·3	38·4	·25	2·22	40·6	
5	38·1	38·2	·24	2·46	40·56	40·55
5·5	37·8	38·0	·23	2·69	40·5	
6	37·6	37·7	·23	2·92	40·52	
6·5	37·4	37·5	·22	3·14	40·54	

To find the average cooling per interval of half-a-minute, take falling temperatures about 10 in number after the observed maximum and divide them into pairs: first five and second five, and then subtract the corresponding readings in the following manner:

39·4	39·3	39·1	38·9	38·6
38·3	38·1	37·8	37·6	37·4
1·1	1·2	1·3	1·3	1·2

Hence mean of 1·1, 1·2, 1·3, 1·3, 1·2 which is 1·24 represents cooling per 5 intervals (*i.e.*, 2·5 minutes). Hence average cooling is 0·25°C at the mean of the following temperatures.

39·4, 39·3, 39·1, 38·9, 38·6, 38·3, 38·1, 37·8, 37·6, 37·4.

The mean of all these temperatures is 38·5°C. Hence we may say that the mean cooling is 0·25°C at the mean temperature 38·5°C. Again the cooling is nothing at the room temperature 29·1°C. Further from Newton's law of cooling we know that the rate of cooling is proportional to the excess of temperature and so to the actual temperature. Hence knowing two points on the graph paper we can draw a straight line through these points to obtain the cooling graph (Fig. 119).

Next with reference to this graph, get the cooling at various observed temperatures. The total cooling at any temperature is the sum of all the coolings at the proceeding temperatures and the cooling at the temperature. In this way obtain the final corrected temperatures. It would be found that the final temperature becomes fairly constant after a steady rise. This constant value is the final corrected temperature, which may be obtained by taking a mean of a few values. The chain curve (Fig. 118) is obtained by correcting the radiation loss at every stage of temperature.

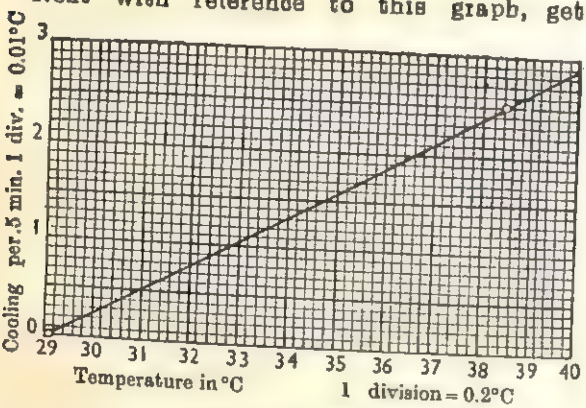


Fig. 119—Cooling-Temperature Graph

Discussions—A sensitive thermometer measuring upto $\frac{1}{5}$ or $\frac{1}{10}$ degree should be used to record the temperature of the mixture. While recording temperature the mixture should be slowly stirred to have uniform distribution of temperature throughout the mass. The following operations are to be done simultaneously: to stir the mixture, to observe the stop-watch and the thermometer and to record the time and temperature. Students. therefore, require a preliminary practice to be able to do this experiment successfully.

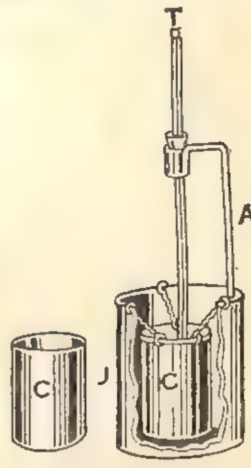
Date— EXPERIMENT 62

To Determine the Water Equivalent of a Calorimeter

Theory—If m gm. be the mass of the calorimeter and stirrer and s the specific heat of the material of the calorimeter, then the water equivalent of the combination is equal to ms gm.

Apparatus—A calorimeter, two thermometers, a glass beaker, some quantity of water and heating arrangements.

A calorimeter consists of a cylindrical copper vessel C, the outer surface of which is polished (Fig. 120*a*). The vessel is often mounted on pieces of cork within another bigger cylindrical vessel made of wood. In some form, the calorimeter is suspended by strings within another bigger vessel J (Fig. 120*b*). This arrangement is for reducing conduction and convection of heat from or to the calorimeter. The outer surface of the calorimeter and the inner surface of the outer vessel are both polished. This minimises loss or gain of heat by radiation. To help the stirring of the liquid, the calorimeter contains a copper ring provided with a handle called a stirrer.



(*a*) (*b*)

Fig. 120

Procedure—Clean and dry the calorimeter with the stirrer, if found dirty, and weigh it in a balance. Measure its mass in a balance to the nearest deci-gramme. Pour a quantity of water into the calorimeter to nearly one-fourth or one-fifth its capacity and weigh again. The difference of masses evidently gives the mass of water taken. Put the calorimeter with its contents inside the casing and clamp a thermometer T vertically so that its bulb remains in water.

Take some quantity of water in a beaker and heat it gently with a burner and note the temperature of water by another thermometer. When the temperature rises about 15°C to 20°C above the room temperature, note the highest temperature and *immediately* take the beaker containing hot water just above the calorimeter and pour almost an equal volume of hot water into the calorimeter.* Stir the mixture well and find the highest temperature of the mixture. When the

* If a correction of radiation loss is required, keep a stop-watch ready. Just at the moment hot water is poured into the calorimeter, start the watch and go on slowly stirring the mixture. Take temperature of the mixture every half a minute until the apparent highest temperature is recorded by the thermometer. Do not stop here taking time-temperature record, but continue to record falling temperatures every half minute for another three or four minutes. Then proceed on with the directions given in the preceding experiment for radiation correction and obtain the corrected final temperature. Draw the cooling temperature graph only.

mixture cools down, weigh the whole thing. Take all weights in this experiment, correct to the nearest decigramme.

Results—(A typical set of observations is given)

The weight of the calorimeter and stirrer =
(i) 78·4 gm (ii) 78·41 gm.
$\therefore$ Mean mass = 78·40 gm = w_1.

The weight of the calorimeter, stirrer and cold water =
(i) 94·61 gm. (ii) 94·63 gm.
$\therefore$ Mean mass = 94·62 gm. = w_2 gm.
The weight of cold water = 16·22 gm. = $w_2 - w_1$
The temperature of cold water = 22·2°C = t_1°C
Initial temperature of hot water = 40·0°C = t_2°C
The common temperature (after radiation correction) = 34·4°C = T°C
Weight of the calorimeter and mixture = 114·40 gm. = w_3 gm.
$\therefore$ The weight of the hot water added = 19·77 gm.
= $w_3 - w_2$ gm.

Heat lost by hot water of mass $w_3 - w_2$ gm. in cooling from t_2° to T°C = $(w_3 - w_2)(t_2 - T)$ calories.

Again heat gained by the calorimeter, stirrer and cold water in being heated from t_1 to T = $(w_1 s + w_2 - w_1)(T - t_1)$

$\therefore$ $(w_1 s + w_2 - w_1)(T - t_1) = (w_3 - w_2)(w_2 - T)$

$$\therefore \quad w_1 s = \text{water equivalent} = \frac{(w_3 - w_2)(t_2 - T)}{(T - t_1)} - (w_2 - w_1)$$

$$= \frac{19{\cdot}77(40 - 34{\cdot}4)}{(34{\cdot}4 - 22{\cdot}2)} - 16{\cdot}22 = 8{\cdot}1 \text{ gm.}$$

Discussions—Some heat is lost by the calorimeter and its contents by way of conduction. Conduction is minimised by placing the calorimeter in a medium which is a bad conductor of heat. Radiation is minimised by polishing the outer surface of the calorimeter and placing it in another vessel of polished inner surface.

To ensure uniformity of temperature throughout the mass of liquid, water should be well stirred while taking the temperature of the mixture. Burners should be kept away from the calorimeter or proper screens should be interposed so that the calorimeter may not receive undesired heat from any source.

The result for water equivalent is better if the value of the water equivalent of the calorimeter is comparable with the mass of water within the calorimeter. Instead of water, if the liquid used be an oil of low specific heat, the result is still better.

Sources of Errors

To avoid highly erroneous or at times absurd experimental results for the water equivalent, the following points are to be carefully remembered.

When the calorimeter and cold water gain heat, the experimental condition for a desired result is to be so arranged that the calorimeter and stirrer absorb heat almost equally as that of cold water. For this reasons the water equivalent of the calorimeter should be nearly equal to the mass of cold water, or in other words the mass of the calorimeter should be 5 to 10 times than that of cold water, according to the nature of the material of the calorimeter.

When the temperature of the mixture rises, there is always some loss of heat by radiation and conduction. The higher is the final temperature, the greater is the loss. When the final temparature exceeds about 10°C above the room temperature, the loss is about half a degree in a well-preserved calorimeter. An error more than this should not be allowed. Hence such a proportion of hot water should be mixed that the final temperature is about 10°C higher than the temperature of cold water.

ORAL QUESTIONS

What is meant by water equivalent of a calorimeter? What is its unit? Distinguish between water equivalent and thermal capacity. What are the sources of errors in this experiment? Why is a calorimeter generally made of copper? You are supplied with two pairs of calorimeters; one pair is of different masses but of the same material; and other pair is of the same mass but one of copper and the other of brass. Compare their water equivalents. How can you avoid highly erroneous or occasionally absurd result in this exp›riment?

EXPERIMENT 63

Date—

To Determine the Specific Heat of a Solid by the method of Mixtures

Theory—If a piece of solid of mass m and of specific heat s at a higher temperature t_2°C be dropped into a calorimeter of water equivalent w containing a liquid of mass w and of specific heat s' at the room temparature t_1°C and if on stirring the mixture the final temperature be T°C (after radiation correction), then from the law of mixture,

Fig. 121

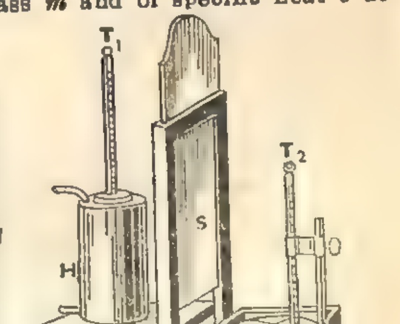


Fig. 122

$$ms(t_2 - \mathrm{T}) = (w + w's')(\mathrm{T} - t_1)$$

$$\text{whence } s = \frac{(w + w's')(\mathrm{T} - t_1)}{m(t_2 - \mathrm{T})}$$

If the liquid supplied be water, then $s'=1$ and the equation reduces to,

$$s=\frac{(w+w)(T-t_1)}{m(t_2-T)}$$

Apparatus—A calorimeter and a stirrer, two thermometers, a steam heater, a piece of marble. a balance and a weight box,

A convenient form of specific heat apparatus, called the Regnault's apparatus, consists of an wooden platform which can be divided into two partitions by a siding board S (Fig. 122) When the board is raised, the communication is established between the two halves of the platform. The box containing the calorimeter (shown to the right) slides over parallel grooves and can be placed on any side of the partition.

Over a small table rests an apparatus called a steam heater C which is also shown separately in section in Fig. 121. A steam heater consists of a double walled cylindrical vessel C having a co-axial air space A The air space between the cylinders has got two openings, one at the top and the other at the bottom. The upper one is used as the inlet for steam and the lower one as the outlet. The upper end of the cylinder is provided with a piece of cork having two openings. The lower end of the cylinder can be closed by a metal plate D whenever required.

Procedure—Take out the calorimeter with the stirrer. Dry, clean and finally weigh it in a balance to an accuracy of first place of decimals in grammes. Take two such masses and find the mean value. Let the mean mass of the calorimeter and stirrer be w_1 gm. If s_1 be the specific heat of the material of the calorimeter, then w_1s_1 is the water equivalent; call it w. Take a quantity of a liquid or water at the room temperature into the calorimeter to about one-third its volume and weigh again to the nearest decigram. Let the mass of calorimeter and contents be w_2 gm Then the mass of liquid taken is w_2-w_1 gm; call it w'. Measure the temperature of the liquid. This gives initial temperature t_1°C Take a piece of marble or any other substance which is supplied and thoroughly clean its surface. Weigh it in a balance and let its mass be m gm. Tie a piece of string with the piece of marble and suspend it within the steam heater as is shown in Fig. 121. Fit up a thermometer T_1 through the other hole of the cork to such a depth that its bulb is very near the suspended body. Take sufficient water into the boiler and connect a rubber tube from the boiler to the steam heater. Heat the boiler. After some time when steam is formed it circulates into the air space A of the cylinder, so that the body is indirectly heated by steam. When the thermometer within the heater records stationary temperature t_2°C near about 100°C, the body attains that temperature.

Now raise up the wooden partition and slide the box containing the calorimeter just beneath the steam-heater. Remove the lower cover plate of the heater and loosen the thread so as to drop the

body into the calorimeter without splashing liquid. Slide back the calorimeter with its enclosure to the other compartment and drop the wooden partition so as to cut off the effects of heat on the calorimeter due to the burner. Stir well the contents of the calorimeter and find the final temperature T°C by another thermometer.

The procedure described above, althought more consistent with the theoretical process of finding specific heat, requires unnecessary time to complete the experiment. It can be done more conveniently in the following way,—

At first take sufficient water in the boiler and connect it to the steam heater. Now take the body, dry or clean it, as may be necessary and weigh it in a balance. By this time steam may be given off. Suspend the body within the steam heater and fit a thermometer, so as to record the temperature of the body. Let the body be heated.

Then take the calorimeter with stirrer, cleanse them if necessary and weigh the combination in a balance. Take the liquid into the calorimeter and find the total mass. By this time the body might show a higher constant temperature. Take initial temperature of the liquid.

Finally drop the body into the calorimeter and get the resulting tamperature.

Results—(typical data)

The weight of the calorimeter and stirrer w_1

(i) 78·4 gm. (ii) 78·4 gm.

Sp. ht. s_1 of the material of the calorimeter (supplied) = ·1

$\therefore$ Water equivalent of calorimeter $= w_1 \times s_1 = w = 7·84$ gm.

The weight w_2 of calorimeter, stirrer and liquid (water)

(i) 106·61 gm. (ii) 106·61 gm.

$\therefore$ mean $w_2 = 106·61$ gm.

$\therefore$ weight of liquid taken $= w_2 - w_1 = w' = 28·21$ gm.

Initial temperature t_1 of liquid $= 21·4$°C

Sp. ht. of the liquid (water) = 1

Weight of the piece of marble

(i) 12·41 gm. (ii) 12·42 gm.

$\therefore$ mean mass = 12·415 gm.

The stationary temperature t_2 of the steam heater = 99°C

The final temperature T of the mixture (after correcting for radiation) = 27·1°C

$$\therefore \quad s = \frac{(w+w_1)(T-t_1)}{m(t_2-T)} = \frac{(7·84+28·21)(27·1-21·4)}{12·41(99-27·1)}$$

Discussions—Although arrangements are made to minimise the effects of conduction from the calorimeter, a small quantity of heat

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* If a correction for radiation is required, the thermometer used to measure the temperature of the mixture should have a graduation of ·2°C or ·1°C. Be ready with the stop-watch. Just at the moment the body is dropped into the calorimeter, start the watch and quickly remove the calorimeter and its contents to the other side and drop the siding board and at the same time introduce the thermometer into the calorimeter. Continue stirring the mixture. The total period in finishing all these things should not exceed 20 seconds. Now after every half minute take the temperature of the mixture and get a time-temperature chart in a manner as shown in Expt. 61. Follow the procedure of obtaining the cooling graph and thence find the corrected final temperature T°C.

is always lost by the calorimeter and its contents due to conduction. Care must be taken to remove the body from within the steam heater into the calorimeter as quickly as possible, without splashing the liquid. The quantity of liquid in the calorimeter should not be taken too large, as then the rise of temperature would be too small Neither the quantity taken should be too small, because then the rise of temperature would be appreciably large and effect of radiation loss would be considerable.

A high percentage of accuracy of result cannot be claimed in an experiment of this kind. The result should be expressed correct to one place of decimal only.

Date EXPERIMENT 64

To Determine the Specific Heat of a Liquid by the method of Mixture

Theory—If a body of mass m and of known specific heat s at a high temperature t_2°C be dropped into a calorimeter of water equivalent w containing a liquid of mass w_1 at a temperature t_1°C and if on thoroughly stirring the mixture, the common temperature be T°C after radiation correction then the specific heat s_1 of the liquid is given by the equation—

$$ms\,(t_2 - \mathrm{T}) = (w + w_1 s_1)\,(\mathrm{T} - t_1)$$

$$\text{whence } s_1 = \frac{ms\,(t_1 - \mathrm{T})}{(\mathrm{T} - t_1)\,w_1} - \frac{w}{w_1}$$

Apparatus—The same as those of preceeding experiment. the calorimetric substance is the given liquid and any solid of known specific heat. The description of the apparatus is the same.

Procedure—The same as the preceding experiment.

Results—The recording of data is also similar.

Discussions—The same.

Oral Questions

Distinguish between thermal capacity and water equivalent of a body. What is meant by the statement "The sp. ht. of copper is 0·1 ?' Define specific heat of a substance. What is the construction of a steam heater ? What is the harm if the solid substance be heated by a current of direct steam in an experiment on specific heat determination ? What are the sources of errors in calorimetric experiments and how to minimise them ?

Latent Heat of Fusion

The latent heat of a fusion of solid is the amount of heat required to convert unit mass of the solid at its melting point into the liquid state without a change of temperature. The same quantity of heat is also given out when a unit mass of the same substance solidifies. Evidently for any substance its latent heat of fusion is equal to its latent heat of solidification. The unit in which the value of latent heat is expressed is kenerally *colories per gm.*

By the statement "the latent heat of fusion of ice is 80° is meant that when 1 gm. of ice at 0°C melts into 1 gm. of water at 0°C, 80 calories of heat are absorbed.

Date— EXPERIMENT 65

To Determine the Latent Heat of Fusion of Ice

Theory—If m gm. of dry ice at 0°C be dropped into a calorimeter of water equivalent m containing w_1 gm. of water at t°C and if when all the ice is melted, the common temperature of the mixture be T (after radiation correction) then the latent heat L of ice is given by the following equation—

$$(m \times \text{L}) + (m \times \text{T}) = (w + w_1)(t_1 - \text{T})$$

$$\text{whence L} = \frac{(w + w_1)(t_1 - \text{T})}{m} - \text{T}$$

Apparatus—A calorimeter and stirrer, a lump of ice, a few pieces of blotting paper, a centigrade thermometer and a suitable clamp, a balance and a weight box.

Procedure—Thoroughly cleanse a calorimeter with a stirrer and weigh it in a balance. The stirrer with a wire gauge netting stretched across the ring is required for this experiment. Now take a quantity of water to about two thirds the capacity of the calorimeter and weigh again. This gives the mass of water taken. Place the calorimeter within its enclo-ure and fix a thermometer vertically so as to read the temperature of water of the calorimeter.

Wash the lump of ice with tap water to remove any dirt and then pound it to small pieces. Wrap up one or two pieces of ice fragments with blotting paper so that no water sticks to it This is called drying of ice. Note the temperature of water within the calorimeter. Then take out the stirrer and drop one piece of dry ice into water. Now lower the stirrer so as to keep the ice immersed in water. Stir the mixture gently so as to keep ice always under water.

A gradual fall of temperature is observed but if the radiation correction is not required, record the minimum temperature. Finally weigh the calorimeter and its contents whence the weight of ice added is known.

If a radiation correction is required, a time temperature record at intervals of one or half a minute is to be taken from the instant of dropping the first piece of ice. The temperature falls at first to an observed minimum and then it continuously rises. About ten rising temperatures are recorded. The rate of gain of temperature is found from this rising time-temperature record. The gain of temperature is substracted from the observed temperature to get true temperature. The method of tabulation and calculation are exactly similar to those of Expt. 61. Only total gain of temperature is subtracted from the observed temperature.

Results—(A typical illustration)

Weight of the calorimeter and stirrer	= 90·1 gm.
,, ,, ,, calorimeter, stirrer and water	= 140·1 gm.
,, ,, ,, water taken	= 50 gm.
Initial temperature of water	= 28°C.
Observed minimum temperature of the mixture (not corrected for radiation)*	= 22·4°C
Sp. ht. of the material of the calorimeter	= 0·09
Weight of calorimeter and its contents when all the ice is melted	= 150·2 gm.
∴ Weight of ice added	= 4·1 gm.
∴ Latent heat of Fusion of ice	= 66·4 cal./gm.

Time in min.	Temp. °C	Mean Temp. °C	Rise of Temp. °C	Total rise of Temp. °C	Corrected Temp. °C
0	28·0	...	...	...	26·08
·5	24·3	23·15	·07	·07	23·46
1·0	23·1	23·7	·17	·24	22·35
1·5	22·6	22·8	·21	·45	21·82
2·0	22·4	22·5	·23	·68	21·59
2·5	22·6	22·4	·23	·91	21·57
3·0	22·8	22·7	·22	1·13	21·56
3·5	23·0	22·9	·21	1·34	21·57
4·0	23·2	23·1	·20	1·54	
4·5	23·4	23·3	...	...	
5·0	23·6	25·5	...	...	
5·5	23·7	23·7	...	...	

The mean corrected temperature after considering radiation loss = 21·75°C (compare uncorrected temperature = 22·4°C) using this as the final temperature of the mixture and substituting in the usual formula, the value of L is found to be 81 cal/gm.

Discussions—Some heat is gained by the calorimeter and its contents by radiation while water is being cooled by ice thus slightly raising the true minimum temperature. This is the principal source of error in determining the value of latent heat of ice; the value being always less due to this cause. There is also a little loss of heat by conduction and convection of air current. The thermometer to be used should be sensitive and should be read avoiding parallax. Pieces of ice to be dropped in should be dry otherwise the amount of water adhering to ice just before dropping will vitiate the result. Too much of ice should not be added because if the minimum temperature of the mixture gets below the dew point, water vapour of the air condenses on the walls of the calorimeter. Such condensation of vapour takes up a considerable amount of heat from the mixture affecting the minimum temperature as also increasing the

* If correction for radiation loss is required, keep a time-temperature record from the instant ice is dropped into the calorimeter. A record of this experiment is given in Experiment 61.

apparent weight of the calorimeter and its contents. The standard value of the latent heat of ice is 80 calories per gramme.

ORAL QUESTIONS

What is meant by latent heat of ice? Explain the various sources of errors in the experiment and methods to minimise them. Does the value of latent heat depend upon the nature of the thermometric scale? If so, how? Explain the defects of the experiment when the ice added is too much or is not properly soaked with the blotting paper.

Latent Heat of Vaporisation

The latent heat of vaporisation of a liquid is the quantity of heat required to change unit mass of the substance at its boiling point from the liquid in the vaporous state without change of temperature. The same quantity of heat is also given out by a unit mass of the vapour in condensing to the liquid state at the boiling point without any change of temperature. The unit of latent heat of vaporisation in C. G. S. system is 'calories per gram.'

Date— EXPERIMENT 66

To Determine the Latent Heat of Vaporisation of Water

Theory—If m gm. of steam at $t°$C condenses within a calorimeter of water equivalent w containing w_1 gm. of water at $t°$C and if the final temperature of the mixture be T°C. (after radiation correction) then the latent heat of vaporisation L of steam at $t°$C is given by the equation,—

$$mL + m(t-T) = (w+w_1)(T-t)$$

$$\text{whence} \quad L = \frac{(w+w_1)(T-t)}{m} - (t-T)$$

Apparatus—A calorimeter and stirrer, thermometer, clamp, balance, weight box, boiler, heating arrangement, a steam trap and connecting tubes.

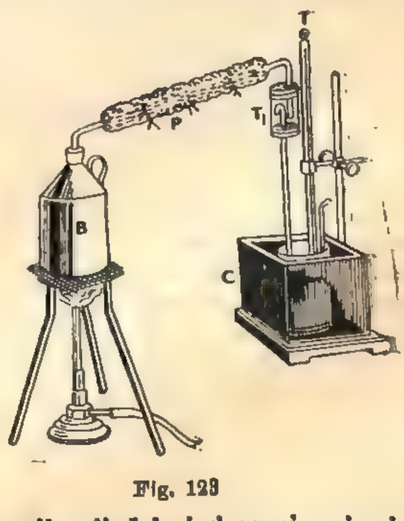


Fig. 123

A boiler B containing some water is placed upon a tripod stand over a Bunsen flame (Fig. 123). A piece of glass tube having its ends bent almost at right angles serves as the outlet for the steam from the boiler. Almost the whole length of this tube is covered with a non-conducting material such as felt or cotton. One end of this pipe is connected with the boiler while the other end passes through a piece of cork into a device called the steam-trap T_1 which consists of a small cylindrical glass pipe having

two stoppers at its ends, each provided with a hole. Through the lower hole of the trap passes another glass tube having its upper end bent and its lower end going into the calorimeter. The function of the steam trap is to arrest any water that might have condensed within the exit pipe and to pass dry steam into the calorimeter.

Procedure—Cleanse the calorimeter and stirrer if necessary and weigh the combination. Take a quantity of water to nearly fourfifths of the volume of the calcrimeter and weigh again. The difference of the masses gives the mass of water taken. Place the calorimeter in its proper position as shown in the figure and fix a thermometer vertically and read the temperature of water. Heat the boiler and when steam comes out copiously, put the end of the glass tube into the calorimeter, such that the nozzle is well within the water. Stir the mixture well and take a time-temperature record at an interval of half a minute or one minute till a maximum temperature of about 20° or 25° above the room temperature is reached. Withdraw the steam jet at once and continue the stirring of the mixture. Take also a number of falling temperatures at an interval of a half a minute. After that take the weight of the calorimeter and its contents, Measure the atmospheric pressure with a barometer. With reference to a vapour pressure Table, find the temperature of steam. Proceed on with the radiation correction as usual and get the corrected final temperature.

Result- (Typical)

The weight of the calorimeter and stirrer	=89·6 gm.
Sp ht. of the material of the calorimeter	=0·1
Weight of calorimeter, stirrer and water	=159·92 gm.
Weight of water taken	=70·28 gm.
Initial temperature of water and calorimeter	=29·5°C
Temperature of the steam (from table)	=99·4°C
Final temperature of the mixture after radiation correction	=55°C
Wt. of calorimeter, water and condensed steam	=162·54 gm.
Mass of steam condensed	=3·63 gm.
∴ Latent Heat of Steam at 69·4°C	=513 cal. gm.
Barometric pressure	=74·6 cm.

Discussion—The condensation of moist steam into the calorimeter entails an error which makes the observed latent heat too low. Another principal source of error is some loss af heat by conduction. The temperature of the calorimeter and its contents should not be allowed to rise by more than 30°C. above the room temperature for in that case, much vapour will be given off from water surface causing considerable loss of heat. The standard value of the latent heat of steam at 100°C is 536 calories per gramme.

ORAL QUESTIONS

What do you mean by latent heat of steam? Does its value change on changing the scale of thermometer or with barometric pressure? What is the distincton between latent heat and total heat of steam? What are the sources

of errors in this experiment? What precautions do you take to minimise various sources of errors? What is the function of the water trap used in this experiment? In case correction for radiation is not made, would the observed value of latent heat be greater or less than the true value? Why?

Expansion of Gases

To state the condition of a gas, it is necessary to mention its *volume*, *pressure* and *temperature* because a change of any one of these affects the other to a marked degree. Of the three variables any two may be changed making the third constant.

(*i*) *Boyle's Law*—Change of volume by change of pressure, temperature remaining constant.

(*ii*) *Charle's Law*—Change of volume by change of temperature, pressure remaining constant.

(*iii*) *Law of Pressure*—Change of pressure by change of temperature, volume remaining constant. (vide, Basu & Chatterjee's Intermediate Physics, Heat, Chap. IV).

Increase of Pressure at Constant Volume—If a given mass of a gas is continuously heated at constant volume, the pressure exerted by the gas is found to increase at a constant rate obeying a definite law which states that *the pressure exerted by a given mass of any gas at a constant volume increases for each degree centigrade rise of temperature by a constant fraction of its pressure at 0°C.* This constant fraction is termed the **pressure co-efficient** of a gas.

Date—

EXPERIMENT 67

To Determine the Pressure Co-efficient of Air at Constant Volume

Theory—If P_0 be the pressure of a given mass of air at 0°C, P_1 that at t_1°C and P_2 that at temperature t_2 and if γ_0 be the pressure co-efficient, then.

$$P_1 = P_0(1+\gamma_0 t_1) \text{ and } P_2 = P_0(1+\gamma_0 t_2)$$

$$\therefore \frac{P_1}{P_2} = \frac{1+\gamma_0 t_1}{1+\gamma_0 t_2} \text{ whence, } \gamma_0 = \frac{P_2 - P_1}{P_1 t_2 - P_2 t_1}$$

Apparatus—Constant volume air thermometer, a beaker partly filled with water, tripod stand and heating arrangements, thermometer and a clamp.

A constant volume air thermometer consists of a large glass bulb at the end of a thick walled capillary glass tube bent twice at

right angles (Fig 124). The capillary tube terminates into a wider tube at the other end. A long piece of stout flexible rubber tubing is connected to the lower end of the wider tube. The other end of the tubing is connected to another glass tube open at the top. The bulb with its attached tube and the open glass tube can be separately moved along vertical uprights on each side of a wooden stand and may be clamped at any position. A vertical scale is either fixed or engraved on the wooden stand. There is either a mark or a small ivory pointer within the glass tube just where the capillary tube widens out. Part of the vertical tubes and the whole of the rubber tubing are filled with pure dry mercury. The bulb and the capillary tube contain air only. The base is provided with levelling screws. In some apparatus a three way key C is fitted by which the bulb can be exhausted of air or can be filled with any other gas.

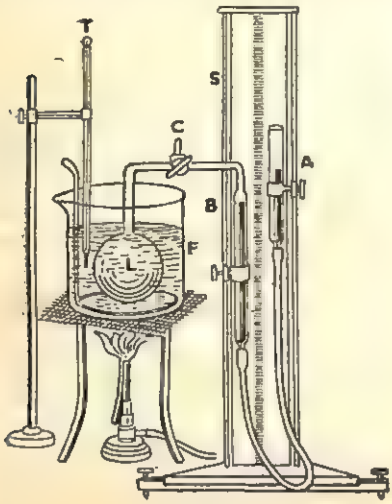


Fig. 124

Procedure—Fill a beaker or a metal vessel almost completely with water and place it upon a tripod stand. Bring down the open end of the apparatus to a sufficiently lower level and clamp it there, care being taken that mercury does not spill from that end. Lower the bulb of the instrument so as to dip completely in water within the beaker as shown in the figure. Clamp a thermometer T vertically to read the temperature of water. Wait for sometime so that the temperature of air inside the bulb attains the temperature of water bath. By raising or lowering the open tube bring the mercury level within the closed tube to touch the ivory pointer and read the mercury levels of the open and closed tubes with reference to the vertical scale attached. Read also the atmospheric pressure from a barometer If the level at A is higher than that at B then the pressure of enclosed air is the sum of the atmospheric pressure and the difference of the levels If, on the other hand, the level at A is lower than that at B, then the total pressure is atmospheric pressure minus the difference of the levels.

Now heat the beaker and stir the water inside slowly. When the temperature rises to some higher value by 30 to 40°C above the room temperature, adjust the flame so as to make the temperature constant for some minutes. Adjust the level of the open tube so that mercury level touches the ivory pointer, Measure the difference of mercury levels and thence find the pressure of the enclosed air at

some known higher temperature. From these two temperatures and pressures, the pressure co-efficient may be found applying the formula.

Results—(Typical)

Reading of the end A (open)	=40·4 cm.
Reading " " " B (closed)	=34·3 cm.
Initial temperature	=28°C
Barometric pressure	=75·8 cm.
∴ Initial pressure P_1 of the gas	=81·3 cm.
Again, reading of the end A	=40·4 cm.
" " B	=53.8 cm.
Final temperature	=55·5°C.
Barometric pressure	=75.8 cm.
∴ Final pressure P_2 of the gas	=89 cm.

$$\therefore \quad \gamma_v = \frac{89 - 81{\cdot}6}{81{\cdot}6 \times 55 \cdot 5 - 89 \times 28} = 0{\cdot}0037 \text{ per °C.}$$

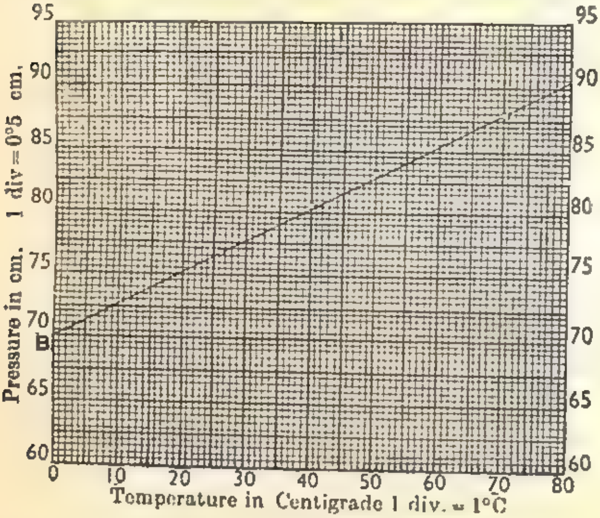
Discussion—The mean value of γ_s for a real gas is 0·00366. Thus the percentage of error is 1%. While carrying out the experiment, care must be taken so that the stopper C is tightly closed. Before taking any reading sufficient time must be allowed for the air inside the bulb to attain the temperature of the bath. This method suffers from a good accuracy inasmuch as the final calculation is made only from two readings. Greater accuracy is attained by extrapolating the value of P_0 from a graph of pressure and temperature at constant volume.

Graphical Method of Determining Pressure Co-efficient—The method consists of the following procedure: Put the bulb of the air thermometer into the water bath at the room temperature and wait for 5 to 6 minutes. Insert also a mercury thermometer into the bath and record the temperature. Now raise the open end A of the mercury column, till the level of closed mercury columns in B touches the ivory pointer. Read the height of the mercury columns.

Now bring a Bunsen burner below the water bath and heat the bath. While the bath is being heated, stir water constantly to ensure a uniform temperature of the bath. When the temperature rises by about 5 to 10°C, adjust the flame to a smaller tip and try to make the temperature of the bath constant for about three to four minutes, slowly stirring water all the while. When the bath temperature remains constant, adjust the level in A so that level in B touches the pointer. Repeating such a process, take five or six readings at intervals of approximately 10°C. Tabulate the results as shown below.

No. of Readings	Temp. of Bath °C	Level in A cm.	Level in B cm.	Difference cm.	Barometric press. cm.	Actual gas Press. cm.
1.	26	50·2	51·0	0·8	75·9	76·7
2.	40	...	54·8	4·6		80·0
3.	50	...	57·2	7·0		82·9
4.	60	...	60·0	9·8		85·7
5.	70	..	62·3	12·1		88·0

Then on a graph paper choose suitable units to represent the temperature of the bath as abscissa and actual gas pressure as ordinate and plot points. Pass a straight line evenly through these points and produce it to meet the pressure axis to a certain point, say B, which gives the pressure corresponding to 0°C. The pressure P_0 according to the method of extrapolation is found to be 70 cm, (Fig. 125). Now taking any point on the graph, find the pressure and corresponding temperature. Taking the temperature of 60°C, the pressure is found to be 85·5 cm. Hence according to the equation,—



Fig, 125—Temperature-Pressure Graph

$$85 \cdot 5 = 70(1 + \gamma_v \times 60) \qquad \text{whence } \gamma_v = 0 \cdot 00369 \text{ per °C.}$$

The advantage of this graphical method is that the result so obtained is the average of a large number of readings and is therefore more accurate.

Oral Questions

If it is called an air thermometer, can it actually measure a temperature? If so, how? Why is a gas thermometer taken as a standard thermometer? Is the coefficient of cubical expansion of all gases the same? Is it possible to find the pressure of the enclosed gas at 0°C without actually maintaining the temperature of the bath at 0°C? If so, how? What is meant by the pressure coefficient of a gas? What is the distinction between a real gas and an ideal gas? Do you know an equation giving the pressure-volume relation of a real gas?

Expansion of a gas at Constant Pressure

It was found by Charles that at constant pressure, the volume of a given mass of a gas increases for each degree centigrade rise of temperature by a constant fraction of its volume at 0°C. This is known as Charles' Law. This relation was afterwards verified by Gay Lussac and more accurately by Regnault.

Date—

Experiment 68

To Determine the Expansibility of a Gas at Constant Pressure by Regnault's Apparatus

Theory—If V_1 and V_2 be the volumes of a gas under constant pressure at t_1°C and t_2°C and if γ_p be the coefficient of cubical expansion at constant pressure,

Then $V_1 = V_0(1+\gamma_p t_1)$ and $V_2 = V_0(1+\gamma_p t_2)$
where V_0 denotes the volume of the gas at 0°C.
From the two equations, we get,

$$\frac{V_0}{V_1} = \frac{1+\gamma_p t_2}{1+\gamma_p t_2} \quad \text{whence } \gamma_p = \frac{V_2 - V_1}{V_1 t_2 - V_2 t_1}$$

Thus knowing V_1, V_2, t_1 and t_2, the value of γ_p can be determined.

Apparatus—Regnault's constant pressure air thermometer a centigrade thermometer, a steam boiler and its accessories.

The apparatus consists of a glass jacket J containing a U-tube AB with its one limb ending in a bulb B while its other limb is open to atmosphere (Fig. 126). The closed limb is graduated in cubic centimetres. A short glass tube C having a stop-cock and passing through the base of the socket is attached to the bottom of the U-tube. There is a copper tube, passing through the base with its both ends outside. There is also a stirrer to keep the mass of water in circulation.

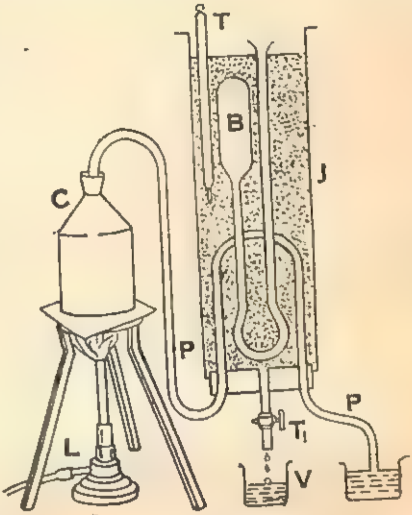


Fig. 126
Constant Pressure Thermometer

The jacket is ordinarily filled with water at the room temperature upto a level that the bulb B is completely immersed in it. A liquid of low vapour pressure, generally sulphuric acid, is contained in the lower part of AB while the upper part of the closed tube is filled with the gas under investigation.

Procedure—Fix a thermometer so as to record the temperature of the water of the jacket. The bulb of the thermometer should be as near to the bulb of U-tube as possible. By pouring in more of the liquid through the open limb or letting out some by opening the tap at T_1 bring the liquid in both the limbs of the U-tube to the same level. The equality of the levels may conveniently checked with a T-scale. The pressure of the enclosed air is then equal to the atmospheric pressure. To be sure of the uniformity of the atmospheric pressure, read a barometer at the beginning and at the end of the experiment. Note the volume V_1 of the enclosed gas and the initial temperature t_1.

Connect the boiler to the copper tube by a rubber tubing and pass steam through the heater tube. The thermometer indicates a slowly rising temperature. Slowly stir the water in the jacket. The gas within the bulb expands and the liquid within the closed limb is found to be gradually depressed downwards.

When the temperature of the liquid is fairly higher, regulate the flow of the steam from the boiler with a pinch cock attached to the rubber tubing so that the temperature becomes stationary for a few minutes, the water being stirred all the while. This is necessary, because air within the bulb and the glass walls being poor conductors of heat, do not immediately attain the temperature of outside water. By opening the stop cock draw out some liquid from the U-tube drop by drop to make the levels of liquid equal. Read the temperature of the bath as well as the volume of the enclosed gas. Hence obtain V_2 and t_2. Thus from the formula calculate the value of γ_p

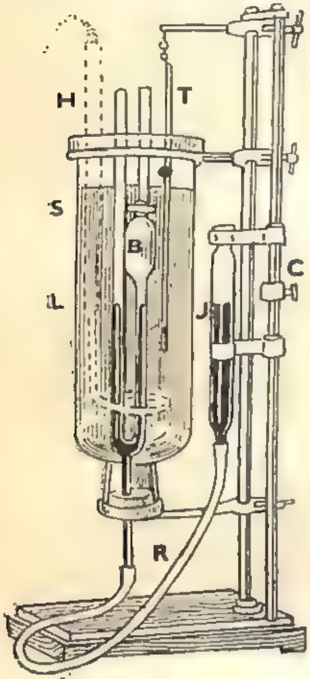


Fig. 127

To get more than one set of readings, raise the temperature of the jacket by an even step of approximately 10°C and make the temperature constant and take the reading of the enclosed air at constant pressure in the usual way. Thus obtain a number of readings from which calculate γ_p The mean value of γ_p gives the coefficient of increase of volume at a constant pressure. Read the barometer again at the end of the experiment. The mean of the two readings gives the average pressure.

A more improved type of apparatus to find the volume co-efficient is shown in Fig. 127. It consists of a glass jacket containing water nearly to the top. An electric heater H is used to heat water and keep it at any desired temperature A glass U-tube containing a bulb B at one limb is placed inside the jacket. There is another tube R connected to the lower bend of the U-tube and this tube terminates in a wider open glass tube J A part of the U-tube and its connected tubing are filled with sulphuric acid. The gas under examination is enclosed within the bulb and is cut off from atmosphere by the stop-cock S. The volume of the gas inside is read by adjusting the height of the open column by the clamp C so that the levels of the liquid within the limbs of U are equal. The experimental procedure and recording of data are similar.

Results —

No. of Readings	Initial temperature	Initial volume	Final Temperature	Final volume	Coeff. of expansion	Mean γ_p
	°C	c.c.	°C	c.c.	per °C	per °C
1.	...	...	...	...	...	
2.	...	...	...	...	...	
3.	...	...	...	...	...	...

Discussions—To maintain a higher uniform temperature of the bath is a matter of delicate and troublesome adjustment. The gas is a bad conductor of heat and consequently to raise the gas inside A to a fixed temperature, the water of the jacket must be kept at that temperature for a few minutes. The expansibility of all gases is fairly constant and its accepted value is 0·00366 per degree centigrade.

Graphical Extrapolation Method—The temperature of the jacket is raised 5 to 10°C above the room temperature and maintained constant for 3 to 4 minutes by regulating the flow of steam and by continuous stirring. The gas within the bulb thereby acquires the temperature of the bath. Immediately the levels of the liquid within the arms of the U-tube are brought to the same level and the volume of the gas as well as its temperature are recorded. In this way by increasing the temperature of the jacket at an approximate even step of 10°C and maintaining the temperature constant for some time at the end of the step, a number of volumes and corresponding temperatures are taken and observations tabulated in the following way:

No. of Readings	Temperature of bath	Volume of gas	Barometric pressure
	°C	c.c.	cm.
1	24	24·5	75·9
2.	30	25·0	
3.	40	25·6	...
4.	50	26·75	...
5.	60	27·5	75·9

The barometer is read at the beginning and the end of the experiment. With suitable units, points are plotted on a graph paper with temperature as abscissa and volume as ordinate. Along the volume axis 5 or 10 small divisions should represent 1 c.c. A straight line is made to pass *evenly* through the points to meet the volume axis at some point A, (Fig 128) which measures the volume of the gas at 0°C. According to the graph. V_0 is found to be 22·3 c.c. Taking any point on the graph, volume at any other temperature is found. This volume so found at 60°C is 27·5 cc. Then from the equation,

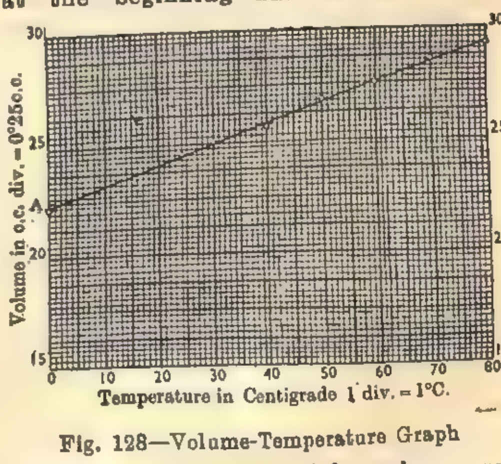


Fig. 128—Volume-Temperature Graph

$$27·5 = 22·3(1 + \gamma_p \times 60), \quad \text{whence} \quad \gamma_p = ·00170 \text{ per °C.}$$

ORAL QUESTIONS

Define Charles' and Boyle's laws. What is your idea about absolute zero? Why is it necessary to adjust liquid levels at an equal height before taking any reading? Why do you maintain the temperature of the bath constant for some minutes before reading the volume of the enclosed gas?

Fusion and Solidification

The fusion is the change of a substance from solid to the liquid state. We ordinarily call this process melting. If any homogeneous solid substance is gradually heated, it is found that a temperature is reached at which melting starts. This temperature remains constant until the whole of the solid melts. When the process of melting is complete, temperature rises again. Therefore, the temperature at which fusion starts and continues to take place until the whole of the solid is converted into liquid is known as the **melting point** of a substance.

Conversely, if a quantity of liquid is continuously cooled, its temperature gradually falls down until at a certain temperature the liquid begins to solidify. The temperature remains constant throughout the process of solidification and is called the **freezing point** of the liquid. It therefore follows that the melting point of a solid is the same as the freezing point of the corresponding liquid provided the outside pressure does not change.

Date—

EXPERIMENT 69

To Determine the Melting Point of a Solid
(By the Capillary Tube Method)

Theory—If a solid is continuously heated, a temperature is reached at which melting starts. Conversely, when the same substance in molten condition is gradually cooled, a temperature is reached at which solidification starts. Both these temperatures are theoretically identical under the same pressure and may be called the melting point of the solid.

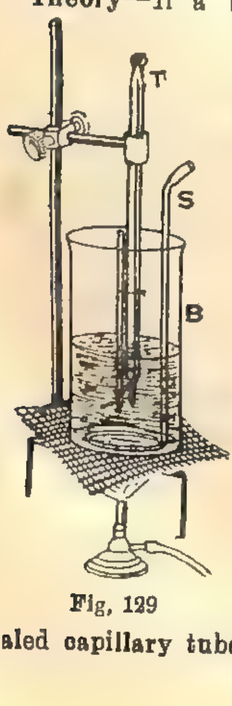


Fig. 129

Apparatus—A beaker, a thermometer, paraffin wax, some quantity of water, thin walled capillary tube and heating arrangements.

Procedure—Take a small quantity of paraffin wax in a basin and heat it. When the paraffin melts, suck a small quantity of it into a thin walled capillary glass tube about 4 to 5 inches in length. On cooling, the paraffin solidifies within the tube. Then seal the lower end of the tube in a Bunsen flame.

Place a beaker half filled with water on a tripod stand as shown in Fig. 129. Tie the sealed capillary tube with the stem of the thermometer so that

the paraffined part is in contact with the bulb. Fix the thermometer vertically with its bulb completely dipping in water and heat the beaker slowly. Stir water continuously and keep a close observation on the capillary tube. When the capillary tubes becomes suddenly transparent, it is an indication that the paraffin has just melted. Note the temperature. Take away the flame and stir the liquid continuously all the while. When again paraffin inside capillary tube looks as a white mass, it is an indication that the paraffin has just solidified ; note the temperature again. Take the barometer reading. Find the mean of these two temperatures which gives the melting point of paraffin at the observed pressure. Repeat the observation at least *three* times and find the mean value.

Results—

No. of Readings	Temperature of meeting in °C	Temperature of solidification °C	Melting point °C	Mean °C	Barometric pressure cm.
1. 2. 3.	58·7 57·8 58 0	57·5 57·8 58·0	58 1 58·4 58 4	58·4	76·2

Discussions—The water is to be heated slowly with a small flame otherwise the rate of rise of temperature is so rapid that it is difficult to observe the temperature at which paraffin just melts. The walls of the capillary tube should be thin as otherwise the temperature of water may not be equal to the temperature of the paraffin. The water while being heated or cooled should always be stirred to ensure a uniformity of temperature. The temperature of melting and freezing should not differ by more than one or two degrees.

Oral Questions

What is meant by melting point of a substance? Why a thin-walled capillary tube and not a thick walled tube is selected to measure the melting point? What is the fundamental difference betweed the solid and liquid state of a substance? Can you account for this difference from the stand point of molecular theory? In finding melting point, why do you take both melting and freezing points?

Date—

Experiment 70

To Determine the Melting Point of Solid
(By Cooling Curve Method)

Theory—If a piece of solid is continuously heated, its temperature rises with time until melting starts. But when melting of the solid once starts, the temperature remains unaltered for some time under a constant pressure. This temperature is the melting point of the solid. Conversely, if the substance in a completely molten state is allowed to cool, the temperature is found to fall with time,

until solidification starts. So long as the solidification continues the temperature does not change. This constant temperature is the solidifying point of the liquid which is identical with the melting point of the corresponding solid.

Apparatus—A beaker, a test tube, a thermometer, some paraffin wax, a clamp, heating arrangements and a stop-watch.

Procedure– Fill about half a test tube with paraffin wax and place it in the beaker partly filled with water. Heat the beaker until the whole of the paraffin wax within the test tube is completely melted and its temperature rises to about 80°C. The quantity of paraffin wax within the test tube should be such that the bulb and a little of the stem of the thermometer should dip into the molten paraffin wax. Stopper the mouth of the test tube *loosely* by a cork with two holes; the central one for the insertion of the thermometer and a side one for a stirrer to pass through.

Take out the test tube from the beaker and clamp it vertically in air. Stir the molten wax slowly and start a stop-watch. Record temperatures at intervals of one or two minutes as the wax cools down. After some time it is observed that the temperature remains very nearly constant for some minutes, indicating that solidification has started. Stir the mass slowly so that heat is uniformly distributed within it. After the whole of the mass is coverted into solid, the temperature again falls with time and take a few falling temperatures after every one or two minutes. Plot a graph with time as abscissa and temperature as ordinate (Fig. 130). The temperature corresponding to the straight part of the graph gives the melting point of the solid.

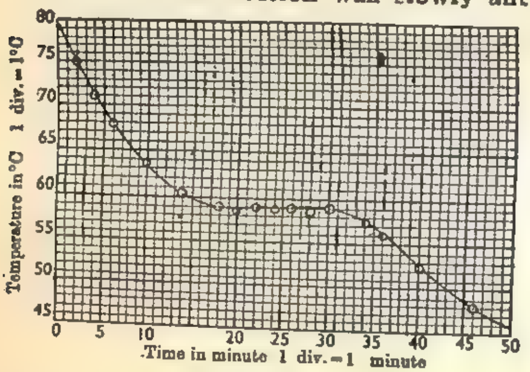


Fig. 130

Results—

Time min.	Temperature °C	Time min.	Temperature °C	Time min.	Temperature °C
0	79	14	60·5	28	58·5
2	75	16	59·5	30	58
4	71	18	59	34	57·5
6	68	20	58·5	36	56
8	65·5	22	59	40	52
10	63·5	24	59	46	48
12	62	26	59	50	46

Hence the melting point of the sample of paraffin = 59°C.

Discussions—The rate of fall of temperature as the substance cools down depends upon the mean excess of temperature of the substance over that of the atmosphere, the quantity of the substance and its specific heat. The duration of the constancy of temperature during solidification depends upon the mass undergoing the change of state and its latent heat of fusion. Hence for a satisfactory set of observations, the quantity of the substance taken should neither be small as then the period of solidification would be too short, nor the quantity should be very large as then the rate of fall of temperature would be too slow.

ORAL QUESTIONS

What is meant by melting point of a solid? What happens to the molecules of the solid when it is in a liquid condition? Why is it that during the process of melting the temperature does not change, although heat is being continuously applied? What process of melting point determination appears to you to be more accurate,—capillary tube method or the lump melting method,—and why?

Hygrometry

The study and measurement of the quantity of aqueous vapour in the atmosphere is called Hygrometry. The formation of dew, fog, rain, etc. sufficiently indicates the presence of water vapour in the atmosphere. The proportion of water vapour in air changes with lowering of temperature of air, and a certain stage is reached at which air becomes saturated with water vapour. At this stage a light fog is formed all above the space or sometimes small drops of dews are deposited on some objects lying in open air. Hence the dew point may be defined as the temperature at which a given mass of air becomes just saturated with the quantity of aqueous vapour actually present in it.

Relative humidity gives us information regarding the proportion of aqueous vapour in the atmosphere. Absolute humidity is defined as the quantity of aqueous vapour actually present in a given volume of atmospheric air and is expressed in grammes per cubic metre of air.

Date—

EXPERIMENT 71

To Determine the Relative Humidity with a Daniell's Hygrometer

Theory—The relative humidity is expressed as a ratio, which is

$$= \frac{\text{Saturation vapour pressure at the dew point}}{\text{Saturation vapour pressure at the room temperature}}$$

This ratio multiplied by 100 gives the percentage of relative humidity.

Apparatus—A Daniell's Hygrometer, a vapour pressure table, a funnel and freezing mixture.

A Daniell's Hygrometer consists of two glass bulbs P_1, B_2 connected with a glass tube bent twice at right angles and mounted on

a vertical stand (Fig. 131). The lower bulb B has on its outer surface a gilt band and contains a sensitive thermometer inside it. Another thermometer T is fixed with the vertical stand. The two bulbs connected by the glass tube contain liquid ether and its vapour only. Whenever necessary liquid ether can be transferred from one bulb into the other by the process of tilting.

Procedure—Tilt the instrument and transfer almost the whole quantity of ether into the bulb B_1. Place the bulb B_2 within a funnel containing a mixture of ice and salt. The bulb B_2 is cooled rapidly and consequently ether vapour in it condenses producing a partial vacuum within it. This causes evaporation of ether in bulb B_1. As more and more vapour condenses in the upper bulb there is a continuous evaporation from within the lower one. This continued evaporation cools the bulb B_1 gradually and ultimately a certain temperature is reached at which a thin film of dew appears on the gilt band. Closely observe the bulb B_1 and mark the instant when the brightness of the gilt band suddenly grows fainter. This is the stage when dew appears on this bulb. Note this temperature from the inside thermometer.

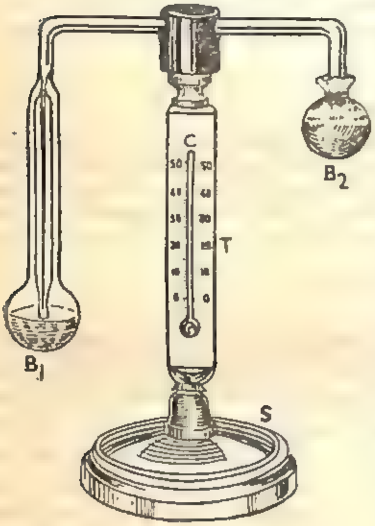


Fig. 131—Daniell's Hygrometer

Take away the funnel containing the freezing mixture. The temperature of the bulb is found to rise gradually. Note also the temperature at which the film of dew point disppears. From the vapour pressure table find the saturation pressure of water vapour at the dew point and room temperature. The ratio of the two gives the relative humidity or hygrometric state. Record three sets of observations and calculate the mean value of temperature. A vapour pressure chart is supplied at the end of this book or it can be had in any book containing Tables of Physical Constants.

Results—(A typical set of data)

Temperature of the Laboratory = 25°C

No. of readings	Dew appears	Dew disappears	Mean Dew point	Saturation press. at dew point	Saturation press. at room temp.	Relative Humidity
	°C	°C	°C	m.m.	m.m.	
1.	15·4	15·5				
2.	...	15·3	15·4	13·12	23·69	0·55
3.	15·4	...				

Discussions—Therefore the percentage of relative humidity in this particular experiment is $0.55 \times 100 = 55\%$. The observation must not be very near the bulb as the hot breath interferes with the formation of dew. It is always advisable to observe the formation of dew from a distance through a telescope. Since a current of air is detrimental to the formation of dew, the experiment should be carried out in a place free from any gusty wind, as otherwise spurious results may be obtained.

Date—

EXPERIMENT 72

To Determine the Relative Humidity by a Regnault's Hygrometer

Theory—The relative humidity is expressed as the ratio which is

$$= \frac{\text{Saturation vapour pressure at the dew point}}{\text{Saturation vapour pressure at the room temperature}}$$

This ratio multiplied by 100 gives the percentage of relative humidity.

Apparatus—Regnault's hygrometer, two thermometers, some quantity of ether.

The apparatus consists of two glass test tubes G, G held vertically on a suitable stand. One test tube (the right side one of the Fig. 132) is connected internally by a hollow pipe P which is connected by a rubber tubing to a large vessed A called the aspirator, provided with a stopcock D at the bottom. Both the test tubes are coated with thin sheets of silver G G and have got air tight rubber corks. Two holes are bored through the rubber cork of the test tubes which has internal connection with the aspirator.

Procedure—Open the stopper of the aspirator and fill it completely with water. Place the aspirator on a flat dish and fit up the stopper tightly. Connect a rubber tubing between the glass tube of the stopper and the pipe of the hygrometer. Pour a quantity of liquid ether into the right side test tube and insert a thermometer T_2 into it through one hole of the cork so that the bulb of the thermometer dips into the liquid. Introduce through the other hole a bent glass tube so that lower end of the glass tube is well inside the liquid. Put another thermometer T_1 into the other test tube through its stopper as shown.

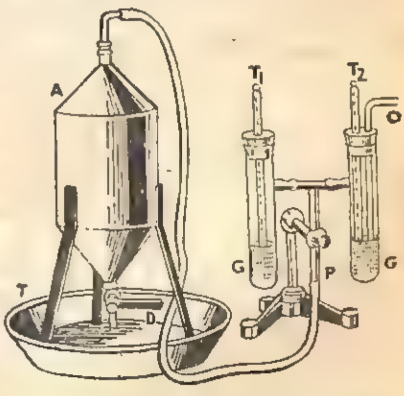


Fig. 132—Regnault's Hygrometer

Now partially open the stop-cock of the aspirator, when water flows down producing a partial vacuum inside it. Atmospheric air rushes through the pipe O into the test tube and thence into the aspirator through the connecting pipes. Air in passing through the test tube bubbles through ether and helps the evaporation of the liquid to a great extent. This produces a continued cooling of the test tube and the temperature of the thermometer T_2 records a gradual fall. Observe closely the silver coating of the gradually cooled test tube and when a film of dew is just formed on this coating, note the temperature of dew formation. Then close the stopcock of the aspirator when the bubbling of ether ceases. The colder test tube now absorbs atmospheric heat and the thermometer T_2 shows a gradual rise of temperature. Note the temperature at which dew just disappears. It is better to stand a few feet away from the test tubes and observe the dew formation through a telescope. The apparatus should be kept away from wind. The mean of the two temperatures gives the dew point. The temperature T_1 records the room temperature all the while.

Results—(A typical set of data is given)

Room temperature = 26·5°C.

Temperature of appearance of dew	= 17°C
Temperature of disappearance of dew	= 17·8°C
∴ The mean temperature	= 17·4°C
Saturation vapour pressure at dew point temperature	= 14·92 mm
" " " " " room "	= 25·69 mm
∴ Relative humidity	= 0·58

Hence the percentage of humidity is 58%.

Discussions—The same as the preceding experiment.

ORAL QUESTIONS

What is meant by relative humidity? Define dew point. What is the distinction between saturated and unsaturated vapours? A space is just saturated with water vapour, what is your idea regarding the dew point temperature? What is meant by vapour tension? Wet clothes dry more rapidly in winter than in summer; explain this.

Dry and Wet Bulb Thermometers

Another type of a hygrometer, known as a Dry and Wet bulb thermometers and widely used for Meteorological purposes, will now be dealt with. It is also called Psychrometer or Mason's hygrometer.

The description of the apparatus is given in connection with the experiment. As water evaporates from the bulb of the wet thermometer, the temperature as indicated by the wet bulb is lower than that of the dry bulb. The difference in the readings depends on the hygrometric state of the air. On a very dry day evaporation would be very rapid and consequently difference of the readings increases. Conversely on a moist day evaporation is slow and the difference is less. Glashier made a systematic study of the difference of tempetures of the thermometers at various conditions of atmosphere and made a tabulated chart giving the relation between the difference of temperatures of the dry and wet bulb and that between the room

temperature and dew point. This relation is called Glashier's factor which is given at the end of the book.

Now-a-days the manufacturers of dry and wet bulb thermometers supply a chart giving the relations between the percentage of humidity and the temperatures of the dry and wet bulb thermometers. This is a ready and more accurate method of finding the relative humidity. A chart of this type is also supplied at the end of this book.

Date— EXPERIMENT 73

To Determine the Relative Humidity by Dry and Wet Bulb Thermometers

Theory—If t_1 and t_2 be the temperatures of a dry and wet bulb thermometers and t the temperature of a dew point, then

$$t_1 - t = F \quad (t_1 - t_2)$$

where F is the Glashier's factor depending upon the temperature of the dry bulb.

Apparatus—A dry and wet bulb thermometer, Glashier's table and Regnault's table.

The apparatus (Fig. 138) consists of two exactly similar mercury thermometers mounted vertically side by side on the same stand. The bulb of one thermometer is freely exposed to air and is designed to record atmospheric temperature, while the bulb of the other is covered with linen which is kept continuously moistened with water by means of a cotton wick dipped into the water kept in a small reservoir P under the thermometer.

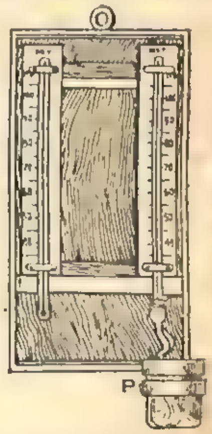


Fig. 138

Procedure—Put sufficient tap water into the reservoir. The wick continuously soaks water and the linen around the bulb of the wet thermometer becomes moist and water evaporates from it producing a lowering of temperature. The difference of the temperatures of the two thermometers depends upon the rate of evaporation of water and consequently upon the proportion of water vapour already present in the atmosphere. Wait for sometime until the temperature of the wet bulb becomes steady. When this is so, record the temperatures of both the thermometers.

After ascertaining the dew point temperature from the Glashier's table, get the saturated vapour pressures at the room temperature and dew point from Regnault's Table, whence relative humidity is calculated. It is essential that the two thermometers should be identical in recording temperatures and as such a comparative calibration of the two thermometers is necessary.

Results—At Calcutta on 27.7.73 at 11 A.M

Temperature of the Dry Bulb $=88^\circ F=31.1^\circ C$

Temperature of the Wet Bulb $=82.5^\circ F=28^\circ C$

Glashier's factor for dry bulb temperature at $31^\circ C=1.64$

Hence $31.1-t=1.64\,(31.1-28)$ $\quad\therefore\quad t=26^\circ C$

From Regnault's Table,

Saturation pressure at the dew point temperature

$26^\circ C=25.13$ mm.

Saturation pressure at the room temperature

$31.1^\circ C=33.76$ mm

Hence Relative Humidity $=\dfrac{25.13}{33.76}=0.74$

or Percentage of Humidity $=74\%$.

Discussions—The experimental determination of the dew point is a very uncertain factor due to very many causes. This method of measuring humidity does not require the determination of the dew point. For this reason, it is accurate and also less troublesome. The other advantage is that a continuous determination of dew point is also possible with this apparatus. There are other forms of Table from which the vapour pressures of water and the percentage of humidity may be directly obtained from the readings of dry and wet bulb thermometers.

Oral Questions

Define hydrometric state of the atmosphere and dew point. What is the usefulness of humidity determination in meteorology? Sweating is copious in a hot and damp atmosphere, explain. Why is the temperature of the wet thermometer generally lower than that of the dry thermometer? When are these two same and why?

Vaporisation and Condensation

The change of state of a substance from the liquid to the vapour or gaseous state is known as vaporisation, while the change of a substance from vapour to the liquid state is known as condensation. According to the circumstances under which it takes place, the process of vaporisation is distinguished as *evaporation* and ebullition or *boiling*.

Evaporation is a slow change from the liquid to the gaseous state which take place *at the surface* of the liquid and *at all temperatures*. Ebullition or boiling is a rapid change of substance from the liquid to the gaseous state which takes place *throughout the mass* of the liquid and at *definite temperature* under given conditions for a particular liquid This temperatue remains constant through out the process, provided the pressure remains unchanged.

Factors influencing Boiling Point—The boiling point of a liquid is found to depend upon,—

(i) the vapour pressure on the surface of the liquid.

(*ii*) the presence of any dissolved impurity increasing the boiling point.

(*iii*) to a small extent on the material of the vessel and degree of cleanness on its inner surface.

The vapour pressure above a liquid at its boiling point is *always equal to the superincumbent pressure.*

Date— EXPERIMENT 74

To Determine the Boiling Point of a Liquid by Bent Tube Method

Theory—The boiling point of a liquid is the temperature at which its vapour pressure is equal to the atmospheric pressure.

Apparatus—A bent glass tube, a metal scale, a thermometer, a beaker, some quantity of mercury and heating arrangements, clamp, stirrer etc.

Procedure—Take a glass U tube of which one limb is closed and the other is open (Fig. 134). The closed limb is shorter and of length 10 to 12 cm. The open limb is of length 25 to 30 cm. The internal bore of the tube may be conveniently 0·5 to 0·6 cm.

Pour some quantity of *pure* mercury into the U-tube so that the level of mercury in both the limbs rises to about 5 cm. Place by means of a pipette a *small* quantity of the liquid on the mercury surface of the open limb. Then by a continuous tilting process transfer the liquid into the closed limb, also remove air from this limb by the same process. When this is done the closed limb contains some liquid at the top and its lower part is occupied wholly with mercury. At this stage it is advisable to put an equal quantity of the liquid at the other limb to balance the hydrostatic pressure of the liquid in the closed limb.

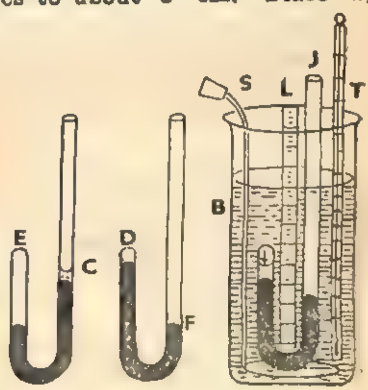


Fig. 134

Now clamp the U-tube vertically within the beaker. Now take some liquid whose boiling point is higher than that of the liquid under test and fill the beaker with the liquid upto a level to immerse the closed end of U-tube completely. Fix the metal scale and a thermometer vertically by the side of U-tube. Place the beaker on a suitable stand and heat it by a small Bunsen flame. Also stir the liquid within the beaker continuously.

It will be found that the mercury in the closed limb continues to descend due to the vapour pressure of the confined liquid. When the mercury levels in both the limbs are equal as seen from the metal scale, read the thermometer. Let it be T_1°C.

Heat the beaker a little more so that mercury in the closed tube is a little below the other mercury level. Remove the burner and the liquid is allowed to cool, stirring being continued all the while. The mercury in the closed limb is found to rise. Record the temperature when again mercury levels are equalised, Let it be T_2°C. The mean of these two readings gives the boiling point of the liquid. Repeat the observation three times.

Results—

Barometric Height =

No. of Readings	Temperature when heated	Temperature when cooled	Mean Temperature	Mean Boiling point
	°C	°C	°C	°C
1.	...	...	...	
2.	...	...	...	...
3.	...	...	...	

Discussions—This method has got many advantages over other methods of determining boiling points inasmuch as a very small quantity of liquid is sufficient. But it is often a matter of difficulty to remove air completely out of the closed limb of the tube. Moreover a change of boiling point with a small change of pressure can be studied. Boiling point of inflamable liquids can be studied by this method without any risk of explosion. It is equally applicable in solutions or pure liquids.

ORAL QUESTIONS

What is the distinction between boiling and evaporation? What is vapour pressure of a liquid? What is the distinction between saturated and unsaturated pressure? How does the boiling poing depend on pressure? What is the effect of the solvent on the boiling point? What is the advantage of the J-tube method over ordinary methods of measuring boiling point?

Heat and Work

It is a common observation that as work of the nature of friction or impact is done, heat is developed. The more work is the done the larger is the amount of heat developed.

The generation of heat by mechanical work and the production of work by heat show an intimate relation between heat and work. A definite amount of work must be done to produce a definite quantity of heat. The relation is expressed as the First Law of Thermodynamics, which is stated as follows, after Maxwell.—

"*When work is transformed into heat or heat into work, the quantity of work is mechanically equivalent to the quantity of heat*". If an amount of work W produces a quantity of heat H,

$$\text{then } W \propto H \text{ or } W = JH$$

where J is a constant after the name of Joule who first measured it. If H = 1 calorie, then J is equal in magnitude to W.

Hence this constant J is the energy equivalent to the unit of heat and is termed the Mechanical Equivalent of Heat or Joule's Equivalent. There are various methods of measuring J.

The accepted value of J in British Thermal Units (B. Th. U.) is 778 ft. lbs. per pound-degree fahrenheit unit and in C. G. S. unit $4{\cdot}19 \times 10^7$ ergs per caloric. For details vide Basu & Chatterjee's Intermediate Physics Vol. I Heat.

Date— EXPERIMENT 75

To Determine the Mechanical Equivalent of Heat by Searle's Apparatus

Theory—The amount of work required to generate a unit of heat is known as the mechanical equivalent of heat or Joule's equivalent and is denoted by J. In the C. G. S. system, J is defined as the amount of work in ergs needed to generate 1 gram-caloric of heat.

In the friction cone method of determining the mechanical equivalent of heat.—

$$J = \frac{2\pi n Mgr}{(ms + m_1 s_1)(\theta_2 - \theta_1)} \text{ ergs per caloric,}$$

where n = total number of revolutions of the cone.
M = load in gm. suspended from the pulley.
g = acceleration due to gravity in C. G. S. units.
r = radius of the cover disc.
m = mass of the calorimeter with its attachments.
s = sp. ht. af the calorimeter with its attachments.
m_1 = mass of the liquid within the calorimeter.
s_1 = sp. ht. of the liquid.

Apparatus—Searle's mechanical equivalent apparatus, a sensitive thermometer, some quantity of turpentine, stop-watch, a physical balance and weight box.

The apparatus consists of two hollow truncated cones C and C_1 of copper or brass fitting into each other (Fig. 135). A thin circular wooden disc D with a central hole is screwed to the top of the inner cone C_1 which serves as the calorimeter. The outer cone C is fixed through an ebonite rod to a horizontal pulley near the base, which can be rotated by means of belting b going to a hand wheel W (Fig. 136). In some apparatus the rotation is effected by a controllable electric motor. The rod supporting C is held in sockets B_1 and B_2 containing ball-bearing arrangements. A cord is wound round the circumference of the disc E, the end of which passes over the pulley and carries a mass M at its end. There is a speed counter S attached to the revolving shaft, which measures the number of revolutions of the cone per minute.

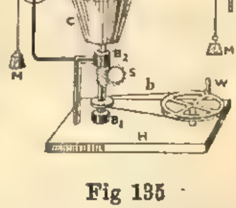


Fig 135

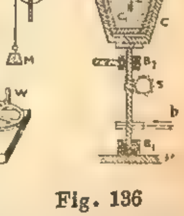


Fig. 136

Procedure—The whole procedure is divided into two parts, the first part being preliminary adjustment. Take out the pair of metal cones and weigh the combination in a balance. Fill the inner cone to about three-fourths the volume with turpentine. Then mount the combination on the revolving shaft and screw up the wooden disc properly with the load M. Fix a thermometer capable of reading $\frac{1}{5}$ or $\frac{1}{10}$ degree into the central hole, so that its bulb dips into the liquid.

Measure the temperature of turpentine. Then start the motor coupled to the wheel W to secure a rotation of the outer calorimeter and start the stop-watch. Then load M is found to rise up through a certain height and then to remain stationary so long as the rotation takes place. The thermometer records a rise of temperature the rate being proportional to the speed of revolution of the outer cone. Adjust the speed of rotation of the motor until the temperature rises by about 70 to 80° in an interval of 3 to 4 minutes.

When the proper speed of revolution has been secured, the real experiment is done in the following way. Discard the heated turpentine and freshly fill the cone with cold turpentine about the same volume and weigh again. Then fit up the cone with the shaft. Simulnaneously start the motor and a watch. When the desired highest temperature is reached, stop the motor and see the time. If the apparatus is not provided with an electric motor, the wheel must be rotated with the hand in such a way that the weight is raised to constant height during the course of heating of the liquid. Slight jerking of the cones in revolution automatically serves the purpose of stirring. Repeat the experiment three times with freshly filled turpentene each time. When the highest temperature, say θ is reached, the calorimeter and its contents begin to cool. Take the time-temperature record and hence find the time t required to cool through 1°C. If θ be the room temperature, the then the loss of temperature l by ratiation is given by the form.

$$l=\frac{t}{T}\times\frac{\frac{\theta_r+\theta'}{2}-\theta_r}{\theta'+\theta'},$$

where T represents the interval during which the friction cone is made to revolve to generate heat.

Hence $\theta'+l=\theta_2=$ corrected temperature.

Results (Typical set)

The mass of the pair of cones	=186·2 gm.
The mass of cone and turpentine	=311·4 gm.
The mass of turpentine	=125·2 gm.
Sp. ht. of the material of the cone	=0·1
Sp. ht. of turpentine	=0·5
Diameter of the wooden disc	=9·2 cm.
∴ Radius of the disc	=4·9 cm.
Number of revolutions per minute	=104
Period of revolution	=3 mins.

Initial temperature of calorimeter and contents	$=26\cdot4°C$
Final temperature of calorimeter and contents	$=31\cdot4°C$
Time to cool 1°C from final temp.	$=2\cdot4$ min.
Radiation correction	$=0\cdot4°C$
Final corrected temperature	$=31\cdot8°C$
Load at the end of the string	$=2$ Kgm.

Work done $=2\times3\cdot14\times4\cdot6\times104\times3\times2000\times981$ ergs.

Heat produced $=(116\times\cdot1+125\cdot2\times\cdot5)\times(31\cdot8-26\cdot4)$ cals.

$$\text{Hence } J=\frac{2\times3\cdot14\times104\times2000\times981\times4\cdot6\times3}{81\cdot21+94}$$

$$=4\cdot0\times10^7 \text{ ergs/calorie,}$$

Discussions—There is some loss of heat due to radiation which may be corrected; but there is also some loss of heat due to conduction through the supporting rod etc. Some little amount of energy is lost due to vibration of the apparatus and some due to sound produced during rotation.

ORAL QUESTIONS

Define mechanical equivalent of heat and mention its unit. What is your idea regarding the nature of heat? Cite a few very common illustrations in which frictional work is converted into heat. Is there any change in the observed value of J, if the space between the cones is lubricated? Explain. What are the effects of radiation and conduction losses on the observed value of J? Does the value of J change on changing the system of units?

Date— EXPERIMENT 76

To Measure the Mechanical Equivalent of Heat by Callender's Apparatus

Theory—The mechanical equivalent of heat is the amount of mechanical energy (usually measured in ergs or joules) required to produce one unit of heat energy (usually one gram-calorie) in the C. G. S. system. The ratio of mechanical energy spent (work done) and the heat developed is also known as Joule's constant J.

In the particular type of Callendar's apparatus,—

$$J=\frac{2\pi rn(M-m)g}{(ms+m_1s_1)(\theta_1-\theta_1)} \text{ ergs per calorie}$$

when n = number of revolutions during course of observation

r = radius of drum

M = load attached to the hand

m = spring balance reading during 'float'.

g = acceleration due to gravity

m = mass of liquid within drum

s = specific heat of liquid

m_1s_1 = water equivalent of the drum

Apparatus—Callendar's mechanical equivalent apparatus, a sensitive thermometer, a stop watch, some quantity of liquid, a physical balance and weight box.

The apparatus consists of a hollow metal drum D kept in a horizontal position and is capable of being rotated along a horizontal axis at any desired speed by means of a pulley and belting arrangement coupled to an electric motor (Fig. 137). A band of silk T is attached at one end to a spring balance B and is wrapped round the drum, the other end of the band carries a cross-piece to which a load can be suspended. A speedometer is fitted for measurent of rotation. The apparatus in perspective is shown in figure 138.

Procedure—Take out the drum and cleanse it. Measure the mass of the drum with the balance supplied. Take two such weights and find the mean. Now refix the drum and wound round the silk band and put a known load of 3 to 4 kilograms. When the drum is free to rotate, the spring balance would fairly record such load. Now start the motor and couple the pulley so that the drum rotates and the frictional force between the band and the drum tends to raise the load. The spring balance now records a decreasing pull. Increase the speed of the motor slowly till the spring balance records a low and a constant reading. The opposing frictional force nearly balances the load. The load at this stage is technically called 'floating' due to friction.

Fig. 137

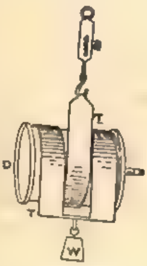


Fig. 138

Now allow the drum and the silk band to attain the laboratory temperature. Use a pipette and introduce through the hole of the drum a measured volume of water of mass of about 150 to 200 grams. Introduce also the bulb of a centigrade thermometer with a rubber stopper into the hole which also makes the drum water tight. Read the initial temperature. Then start the motor and allow the drum to rotate at a constant speed for 5 or 6 minutes with the load in a 'floating' state. Read the spring balance every one minute and record the readings.

After stopping the motor read the final temperature of water within the drum. If necessary a cooling correction may be applied as given in the previous experiment.

Results—(A typical set)

Mass of copper drum = 430 gm. (mean value)

Water equivalent = 430 × ·09 = 38.7 gm.

Capacity of the pipette = 20 c c

10 pipette-fulls of water introduced

∴ Volume of water introduced = 200 c.c.

or Mass of water within drum = 200 gm.

Load = 4 kgms. = 4000 gm.

Spring balance readings = 88 gm., 90 gm., 91 gm., 90 gm., 89 gm.

$\therefore$ Mean reading = 90 gm.
Diameter of Drum = 12 cm., 11·9 cm., 12 cm.
Mean diameter = 12 cm.
Revolutions per minute = 80
Total revolutions in 5 minutes = 400
Initial temperature = 20·4°C.
Final temperature = 26·3°C.

The rise of temperature was small and so radiation correction was not taken into account as it would be too small.

Now mechanical work done $= (4000-90) \times 980 \times 3{\cdot}04 \times 02 \times 400$ ergs and heat generated $= (200+31{\cdot}7)\ (26{\cdot}3-20{\cdot}4)$ calories.

$$\therefore \quad J = \frac{3900 \times 980 \times 3{\cdot}04 \times 02 \times 400}{238{\cdot}7 \times 5{\cdot}9} = 4{\cdot}0 \times 10^7 \text{ ergs/calorie}$$

Log calculations :

log	3910	= 3·5922	log 238·7	= 2·37 1	
log	980	= 2·9907	log 5·9	= ·7709	
log	12	= 1·0792	10·7620	3·0480	
log	400	= 2·6021	3·1490		
		10·7621	anti log 7·6131 = $4{\cdot}1 \times 10^7$		

Discussions—The largest possible error arises in the measurement of temperature differences. Although a one-tenth degree centigrade thermometer was used, there might be an error ± ·1°C in reading any temperature. So the maximum error in reading a temperature difference of 5·9°C might be 0·2°C which equal to an error of 0·4%. A little amount of heat is absorbed by the silk band as well as another little amount is conducted to the rotating shaft in addition to the amount lost by radiation. All these losses will not entail an error more that in temperature measurement.

ORAL QUESTIONS

Questions in addition to those of previous experiment. Cite a practical illustration in which heat is converted into work. Is it practically possible to convert whole of available heat into work? If not, why this is so. When electrical energy is converted into heat, is there a fixed relation between the two quantities like heat and mechanical energy? Do you know of any case in which magnetic energy is converted into heat?

Date—

EXPERIMENT 77

To Measure the Specific Heat of a Liquid by the Method of Cooling

Theory—If a calorimeter of water equivalent w containing m gm. of water takes t_1 minutes to cool from θ_2°C to θ_1°C, then

$$(w+w)\ (\theta_2-\theta_1) = t_1 R$$

where R is the average heat energy emitted per minute from the surface of the calorimeter.

If the same calorimeter containing an *equal volume* of some other liquid of mass m_1 gm and sp. heat s_1 takes t_2 minutes to cool for the same range of temperature, then also

$$(w+m_1s_1)(\theta_2-\theta_1)=t_2R$$

$$\therefore \quad \frac{t_1}{t_2}=\frac{w+m}{w+m_1s_1} \text{ whence } s_1=\frac{t_2(w+m)}{t_1\ m_1}-\frac{w}{m_1}$$

Apparatus—A calorimeter with stirrer, measuring cylinder, balance and weight box, a sensitive thermometer, an ordinary thermometer, water, kerosene and heating arrangements.

Procedure—Find the mass of the calorimeter and stirrer to the nearest decigram. Take two separate readings of the mass and find the mean value. Take about 75 to 80 c.c. of water in a measuring cylinder and carefully find its volume. Pour the whole quantity of water into the calorimeter and weigh again. Take two such weights. The difference gives the mass of water taken. Place the calorimeter with its contents on a sand bath and slowly heat the temperature of water inside being measured with an ordinary thermometer, When the temperature of water rises to about 30°C above the room temperature, take out the calorimeter and put it in its proper casing. Fix up a centigrade thermometer into it and stir the liquid continuously but slowly. Start the stop watch and take a record of falling temperatures at intervals of a minute till the temperature comes down to about 5 to 6°C above room temperature. Again, take water out of calorimeter into the measuring cylinder and find its volume.

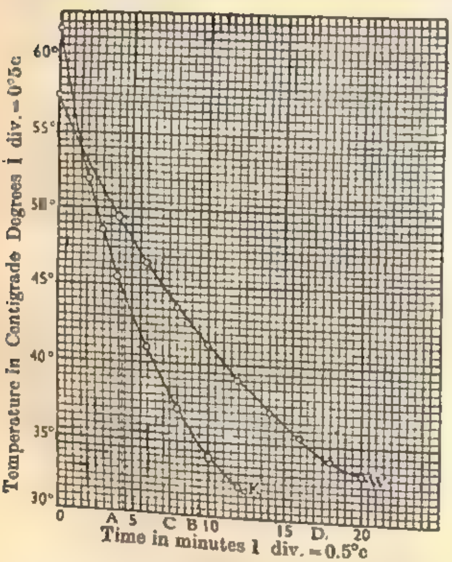


Fig. 139—Cooling curves for two Liquids

With the help of the measuring cylinder, take an equal volume of kerosene into the calorimeter and weigh again. Take two such weights. In a similar way, heat the calorimeter with kerosene to about 30° above the room temperature and allow it to cool down. Take the time-temperature record of falling temperatures. Draw the cooling curves of the two liquids on a graph paper (Fig. 139). Finally, find the time required for the liquids to fall through an equal range of temperature from the graph.

Results—

Mass of the calorimeter and stirrer (mean)	=90·2 gm.
Mass of calorimeter, stirrer and water (mean)	=164·6 gm.

Mass of calorimeter, stirrer and kerosene (mean) $=140\cdot7$ gm.
Volume of each liquid taken $=75$ cc.

Time-Temperature Chart

Water				Kerosene			
Time min.	Temp. °C	Time min.	Temp. °C	Time min.	Temp. °C	Time min.	Temp. °C
0	57·50	8	43·6	0	61·6	7	39·0
1	55·25	10	41·3	1	56·3	8	37·2
2	53·10	12	49·0	2	52·0	9	35·5
3	51·1	14	37·1	3	49·1	10	34·0
4	49·5	16	35·4	4	45·5	11	33·0
5	48·0	18	34·0	5	43·2	12	32·0
6	46·5	20	33·2	6	41·0	13	31·2

Time t_1 required for water to fall from 45° to 36°C = 9·5 min.

Time t_2 required for kerosene to fall from 45° to 36°C = 5·0 min.

$$\text{Hence } s_1=\frac{5}{9\cdot5}=\frac{90\cdot2\times1+74\cdot4}{59\cdot5}-\frac{90\cdot2}{59\cdot5}=\cdot58$$

Discussions—Since the rate of cooling depends on the emissivity of the surface, time and temperature, it is independent of the nature of the liquid kept within the calorimeter. The liquid must not be heated much above the room temperature. Equal volume of the liquid must be taken each time as then the surface emissivity would be the same.

Thermal conductivity

The total quantity of heat Q flowing through the meterial is (*i*) directly proportional to A, the area of cross-section, (*ii*) directly proportional to $(\theta_2-\theta_1)$ difference of temperatures between the faces, (*iii*) directly proportional to the time t in secs., (*iv*) inversely proportional to the length l of the material.

$$\text{Then } Q\propto\frac{(\theta_2-\theta_1)\ At}{l}\quad\text{or}\quad Q=K\frac{A\ (\theta_2-\theta_1)\ t}{l}$$

where K = thermal conductivity of the material.

The thermal conductivity of a material is the quantity of heat that flows in one second through unit area of a slab of that material of unit thickness, the difference of temperatures between the faces being unity and the flow of heat being normal to the faces.

The thermal conductivity of metals is higher than that of non-metallic solids. With the exception of mercury and metals in the molten state, liquids in general are bad conductors of heat. The conductivity of gases in extremely low.

Date—

EXPERIMENT 78

To Determine the Thermal Conductivity of a Metal by Searle's apparatus

Theory—If two ends of a material of length l and cross-section A are maintained at temperatures θ_2 and θ_1, then the amount of heat Q flowing from the hotter to the colder end in t seconds is given by,

$$Q = \frac{KA(\theta_2 - \theta_1)t}{l}$$

when K is the thermal conductivity of the material.

To measure Q, cold water is made to circulate round the colder end of the material through a pipe and if θ_3 and θ_4 be the temperatures of water at the inlet and outlet of that end and a mass m of water circulates in t secs,

$$\text{Then } Q = m\,(\theta_4 - \theta_3) = \frac{KA(\theta_2 - \theta_1)t}{l}$$

$$\text{whence } K = \frac{ml(\theta_4 - \theta_3)}{At(T_2 - T_1)}$$

Apparatus—A Searle's conductivity apparatus, a fixed pressure water tank, four sensitive thermometers, a beaker, a stop-watch, a balance and weight box, a slide callipers.

The conductivity apparatus consists of a short uniform cylindrical metal bar wrapped up with a thick coating of felt within an wooden box (Fig. 140). One end of metal bar is placed in a small chamber S having two openings fitted with rubber tubes. Steam from a boiler can be passed through one rubber tube into the chamber and thereby one end of the bar is heated. The other tube serves as the outlet for steam. The other end carries a thin copper coil C through which cold water can be circulated from a fixed pressure water tank R. The two ends of the coil have got two water tight recesses for the insertion of thermometers, which record the temperatures of incoming and outgoing water from the coil. There are two holes A and B bored within the bar at its two ends for the insertion of thermometers to record the temperature difference.

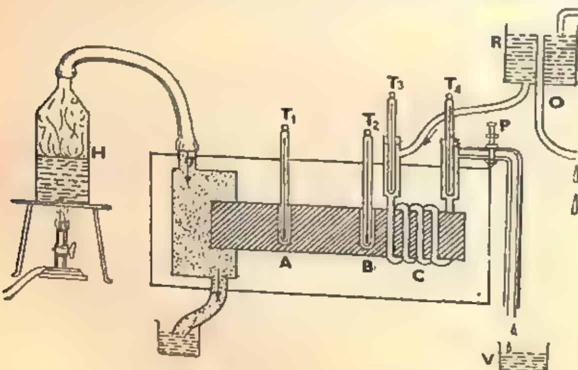


Fig. 140—Searle's Conductivity Apparatus

Procedure—Take the metal bar out of the box and measure its diameter at four or five different places with the slide callipers. Measure with a metre scale the distance between the centres of the two holes on the bar. Take two or three such readings for this distance.

Then place the rod as usual within the box and connect the steam chamber with a rubber tubing to the boiler containing water.

The outlet pipe for steam should preferably be dipped in water and kept in a separate reservior, in order that steam issued may not unnecessarily be deposited on the table or the surroundings.

Connect the delivery pipe of the fixed pressure water tank by a rubber tubing to the inlet pipe of the copper coil, and another tubing between the outlet pipe of this coil and the sink. Fit up four thermometers, two on the metal bar and another two at the ends on the copper tube. by means of rubber stoppers.

Heat the boiler to get a continuous supply of steam which heats the end of the bar. Attach a pinch cock to the outlet pipe for water in order that water is made to circulate through the colder end in a small stream. When the thermometers T_1 and T_2 at A and B record nearly stationary temperatures, adjust the pinch cock P so that the difference of temperatures as read by thermometers T_3 and T_4 is nearly 5 or 6°C. Watch the temperatures of the inlet and outlet of circulating water (T_3 and T_4) for a while to verify that these two temperatures are constant. Take a dry beaker and weigh it to the nearest decigram. Then place it beneath the outlet for water and simultaneously start a watch. Collect water for a known interval, say, two or three minutes. Record the temperatures of the thermometers T_1, T_2, T_3 and T_4 which ought to give constant readings while the water is being collected. Finally, find the mass of the beaker with collected water.

Results—

Mean diameter of the bar	= 4·1 cm.
Distance between two holes	= 7·6 cm.
Temperature of the hot end of the bar	= 83·6°C
Temperature of the cold end of the bar	= 70°C
Temperature at the inlet	= 31·5°C
Temperature at the outlet	= 44·5°C
Mass of the empty beaker	= 71·72 gm.
Time of flow of water	= 2 min.
Mass of the beaker and water	= 280·66 gm.
∴ Mass of water collected in 2 min. (120 sec)	= 208·94 gm.

$$\text{Therefore } k = \frac{208{\cdot}94 \times (44{\cdot}5 - 31{\cdot}5) \times 7{\cdot}6}{3{\cdot}14 \times (2{\cdot}05)^2 \times (83{\cdot}6 - 70) \times 120} = 0{\cdot}92 \text{ cals. per cm.}$$

per deg. per sec.

Discussions—The constancy of temperatures of the thermometers is a matter of importance. For greater accuracy all four thermometers are to be compared and calibrated by placing them in a bath of variable temperature. The conductivity of the circulating coil C is a matter of some consideration, which should be very thin and made of the same materials as that of the bar or should be made of highly conducting material such as silver or copper.

ORAL QUESTIONS

Define conductivity of a solid and give an idea regarding the nature of conductivity. Is conduction possible in a liquid, how? Distinguish cleary between the three processes of transmission of heat. Why does a piece of stone feel colder to be touch than a piece of wood? Explain the function of the warm clothing for protection against chill. Is Searle's method of measuring conductivity suitable for materials such as glass? If not, why?

Heat Engines.

Heat Engines are a class of machines in which heat energy is converted into mechanical energy and work is therefore derived from heat. To this class belong Steam Engine, Steam Turbine, Internal Combustion engines including Oil or Gas Engines, Petrol Engines etc. These are sometimes called Prime Movers.

Date—

EXPERIMENT 79

To Study the Action of a Model Steam Engine

Apparatus and Principle of Working—In essential parts, the machine consists of a boiler L in which water is converted into steam by a suitable furnace (Fig. 141). This unit is kept separate from other parts of the engine and so is the name External Combustion Engine. The boiler is provided with a safety valve N which limits the maximum pressure of steam within it and so the safety valve protects the boiler from any damage by excess pressure. The principle of a safety valve is that a valve presses upon an opening of the boiler by force applied by lever having its fulcrum at F and a load G at its end. When the steam pressure within the boiler exceeds a critical value adjusted by the safety valve device, the force on the valve by the steam raises the valve from its seat allowing an escape of the steam. The quantity of steam within the boiler is thus reduced and its pressure falls when the valve closes again.

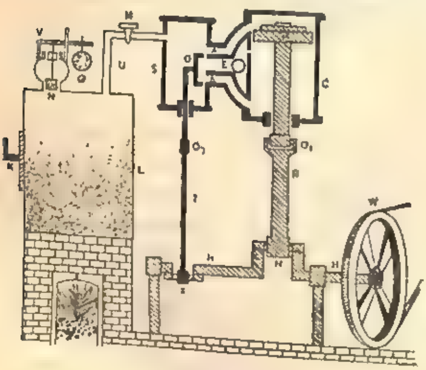


Fig. 141

The steam from the boiler at some fixed pressure is led through metal pipe into a device known as the steam chest or a valve chest S. It is a cylindrical or rectangular stout metal box rigidly fixed to the cylinder of the engine. Just opposite to the inlet pipe the steam chest is provided with three openings or *ports* side by side. The two extreme ports connect the steam chest to the ends of the cylinder, and the middle one is connected to the exhaust. These two communicating ports are alternately opened and closed by a stout metal valve called the Slide Valve or D-valve. The shape of the valve is such that in any extreme position it allows steam to pass into the cylinder through one port while it connects the other port to the exhaust E.

The cylinder is made of mild steel and is capable of standing a high pressure. The joints are made air-tight except an opening at one end through wich a sliding iron rod known as the piston rod passes. There is a packing in between the rod and the opening which prevents leakage of steam The packing unit is called the stuffing box. A steam tight stout steel disc called the piston P is firmly screwed on to the piston rod. The piston is capable of sliding to-and fro within the cylinder. The piston rod is connected with the driving rod at the cross-head by a pin called the gudgeon pin. The driving rod in its turn is connected to the crank H by a crank pin. The crank which is rigidly connected to the shaft is a contrivance by which the to-and-fro motion of the piston rod is converted into the rotatory motion of the shaft. The D-valve has also a rod T connected to it. This rod passes through a steam tight stuffing box and is linked to a cross-head through a gudgeon pin. The connecting rod from the cross-head terminates to an eccentric wheel on the shaft. The shaft passes through bearing and carries a heavy flywheel W.

When the steam pressure from the boiler moves the piston alternately in both the directions, it is called a *double acting* steam engine. In order that the engine may not develop too high a speed, it is fitted with a device known as a *governor*. The governor consists of a vertical spindle which is geared to the main shaft of the engine, so that its speed of revolution rises or falls with that of the shaft. Two identical rods carrying two equally heavy balls are connected to the same axle and are connected to a collar by small levers. This collar is connected to another lever, the other end of which controls the valve operating in the pipe connecting the boiler and the steam chest. When the speed of the engine increases, the governor spindle revolves more speedily rotating the balls round it in a circular path. This sets up a centrifugal force tending to throw the balls farther apart. Thus the balls are raised and the collar slides down. The end of the lever in contact with the collar is lowered and its other arm is raised. The throttle valve closes more and more with the speed and controls the flow of steam to the chest.

To explain the principle of action of the engine, a key is opened whereupon superheated steam from the boiler moves into the steam

chest whence it enters the cylinder through the lower port (Fig 142) the slide valve in this position covering the upper port and the exhaust and putting them into communication. The pressure of the steam forces the piston to move forward. The movement of the piston rotates the crank-shaft and the eccentric wheel whereby the D-valve opens the upper port (Fig. 143) and puts the exhaust and lower port into communication. The steam now forces its way through upper port and moves the piston in the backward direction. The steam that formerly went into the cylinder through port no. 1 is now regarded as waste steam and is led outside through port no. 2 and exhaust. The backward movement of the piston gives the crank another half rotation whereby the D-valve assumes its former position

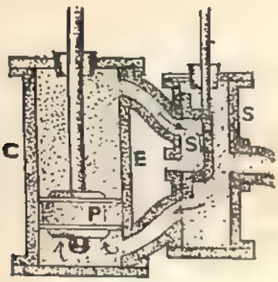


Fig. 142

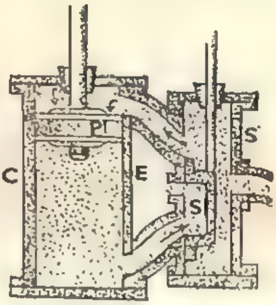


Fig. 143

opening port no. 1. The cycle of operations is repeated over and over again resulting in a continuous circular motion of the shaft. During each revolution of the shaft, there are two positions when the connecting rod and the crank come into the same line; the crank rod in these positions cannot apply a turning moment on the shaft. These positions are called dead centre positions. Again at two other positions the crank and connecting rod are at right angles, when the turning moment is maximum. The torque on the shaft varies from zero to a maximum value during every revolution and this variable torque tends to vary the speed of revolution. To smoothen this variation, a heavy flywheel is mounted on the shaft, which by large inertia maintains a uniform motion when once set in motion.

Oral Questions

What is the difference between an external and an internal combustion engine? What is the function of the boiler of a steam engine? How is the steam led out from the boiler to the steam chest? What is a D—valve and how does it act? What is the function of the governor of a steam engine? What is the function of the fly-wheel of the engine? What is the horse-power?

CHAPTER V

EXPERIMENTS OF LIGHT

Light

Light is defined to be the external physical cause which produces sensation of sight. There are sufficient evidences to show that light may be obtained from various forms of energy, such as electricity, heat, chemical energy etc, as also it may be transformed into other forms. From this we conclude that light is also a form of energy.

A substance through which light can pass is called a *transparent* medium. Bodies in a transparent medium can be seen distinctly. Of course, a portion of the light energy is always absorbed by any transparent medium and more light is absorbed as the energy passes to a greater length of the medium. So body seen through a large thickness of a transparent medium appears hazy. An *opaque* medium is one through which light cannot pass.

Propagation of Light

In 1676, Olaf Romer, a Danish astronomer showed that light energy from a luminous source moves through free space with a velocity of 186.000 miles per second. Subsequent determination of velocity of light through various transparent media has proved that the velocity of light through different transparent media is different.

A medium is said to be *homogeneous* when it possesses the same physical and chemical properties at any point of it. Again a medium is said to be *isotropic* when light is propagated with an equal velocity in all directions from a luminous point source placed any where within it. In a homogeneous isotropic medium light is propagated in straight lines.

A *ray of light* is the path along which light energy propagates. The path is usually represented by a straight line, the direction of propagation is indicated by an arrow head A collection of rays forms *a beam* of light and a narrow beam is termed a *pencil*. A beam may be divergent, parallel or convergent. (vide Basu & Chatterjee's Intermediate Physics, Light, Chap. 1).

Reflection of Light

When a beam of light meets the surface of separation of a medium, a part of the incident light is always turned back. If the surface of the medium is rough or rugged, the light so turned back follows all possible directions, which we call diffusive reflections or surface scattering. But if the surface of the medium be highly polished, the ray turned back from any point of the surface has a specific direction in relation to the incident ray. We call this phenomenon reflection of light.* The ray of light meeting the

* Even if the surface be polished, the mirror must have a minimum dimension to get regular reflection from an incident beam. When the mirror is too small, the reflected beam would scatter in all directions, which we call diffraction.

surface of separation is called the *incident ray*, and the ray turned back is called the *reflected ray* A line drawn perpendicular to the reflecting surface at the point of incidence is called the *normal.*

The laws of reflection can be verified experimentally by Hartle's Optical disc or by the Pin method. (For further details vide Basu & Chatterjee's Intermediate Physics, Light, Chap. II.)

Date—

EXPERIMENT 80

To verify the Laws of Reflection of Light by Pin method

Theory—The two laws of reflection are the following:

(1) The incident ray, the normal to the surface of reflection at the point of incidence and the reflected ray lie in one plane.

(2) The angle of reflection is equal to the angle of incidence.

Apparatus—Drawing board and paper, a few fixing pins, four hair pins, a strip of plane mirror fixed on a vertical stand.

Procedure—Fix up the drawing paper on the board with pins. Draw a fine line with a pencil on the paper and place the mirror with its reflecting plane vertical such that the edge AB of the reflecting surface coincides with the line (Fig. 144). Prick two hair pins vertically on the paper at any two positions P and Q at a distance of about 6 to 7 cm. from each other in front of the mirror such that the line joining PQ is oblique to the reflecting surface. You can easily see the images of the two pins by reflection from the mirror and as you move your head on any side, you may notice how these two images change their relative positions. Now place your eye in front of the mirror in *such a position* that the images of pins in the mirror appear to be in a straight line. Keeping the eye fixed at this position prick one pin at a point S such that the images of the two pins and this pin appear to be in one line. In a similar way fix up a fourth pin at R at a distance of 6 to 7 cm. from S such that the third pin and the images of the first two pins appear to be in a straight line.

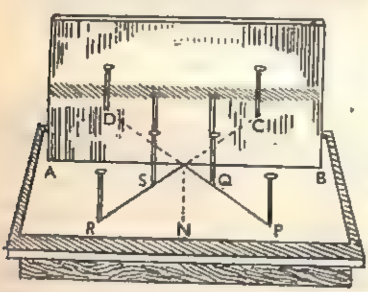


Fig. 144

Remove the pins and join the points P and Q by one straight line and produce it to meet the line AB which is the surface of the mirror at O. Similarly, join the points R and S by the straight line and produce it to meet the surface of the mirror. If the pins have been correctly fixed, this line also would meet at O. Then the line PQO is the incident ray and OSR is the corresponding reflected ray. The nature of the diagram of the drawing paper is shown in

Fig. 145. Reset the mirror *accurately* on the line AB and change the positions of the pins at P and Q to some other points F_1 so that the line joining them meets the mirror surface at a different angle and in a similar manner as already stated, find the corresponding reflected ray. This may be very conveniently done by drawing another straight line OF_1 and fixing two pins along this line. In this way, find the reflected rays corresponding to 4 or 5 incident rays at different angles of incidence. From the point O draw a perpendicular ON on the line AOB. Measure the angle of incidence PON and the corresponding angle of reflection RON with a protractor. If the point of incidence of rays are different, draw a perpendicular at each point of incidence. In each case measure the angle of incidence and the corresponding angle of reflection and tabulate the data.

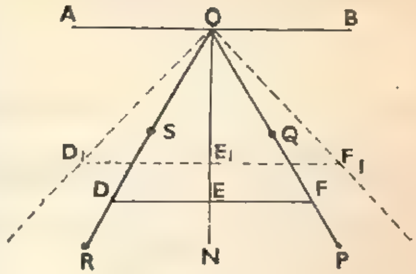


Fig. 145

Results—

No. of readings	Angle of incidence Deg.	Angle of reflection Deg.	Difference Deg.
1.	25	24·5	0·5
2.	...	...	...
3.	45 5	...	0·5
4.	...	60·5	...
5.	72	...	0

The other method of measuring angle is as follows: Through any point E on the normal ON draw a straight line DEF parallel to AB meeting the rays at D and F. If the intercepts DE and EF of this line be equal to each other, then the two angles are equal. This verifies the second law of reflection. Further the points PQSR which are the feet of the pins together with the points O and N all lie on the plane of the drawing board. This shows that the incident ray, the normal and the reflected rays are co-planar.

Discussions—The mirror surface should be accurately plane and mounted vertically so that the pins may be fixed in proper positions. The mirror should be silvered at its front face or at least be very *thin*, otherwise the incident and reflected rays do not meet on the line AB*. The pins should not be fixed very close to the mirror as then a small error in fixing any one pin produces an

* If the mirror is silvered at the back surface, the image seen is due to rays which enter the mirror by refraction at the front surface and get reflected from the silvered surface. The two images by the two surface are seen for much oblique incidence of light due to greater reflecting power of the front surface at this stage.

appreciable error in measuring the angle If the mirror thickness is appreciable and silvered at its back, the line AB may be placed at a distance of two-thirds of its thickness behind the front surface*.

Date—

EXPERIMENT 81

To Determine the Position of the Image of an Object in a Plane Mirror

Theory—The image is as far behind a plane mirror as the object is in front of it.

Apparatus—A mounted small plane mirror, drawing board and paper, a number of hair pins.

Procedure—Fix the drawing paper on the board and draw a straight line AB on the paper (the surface of the board being coincident with the plane of the page). Now, place the mirror vertically so that the line is coincident with the reflecting surface of the mirror. Fix a pin vertically at any point P on the drawing paper in front of the mirror at a distance of 8 to 10 cm. from it. This pin serves as the object. Fix aother hair pin vertically at any point Q between the first pin and the mirror. Now, look into the mirror and move your head until the two pins appear by reflection to lie in one straight line. When this is so, fix two other pins at C and R vertically in such a way that the images of first two pins and this pair are in the same line. Take out all the pins except that at P and join PQ and produce it to meet the surface of the mirror at Q_1 Join also R and C and produce this line to meet the line AB It would be found that these two lines meet at O_1, showing that the incident ray is PO_1 and reflected ray is O_1C. In a similar way by shifting the position of the three pins get two other incident rays PO_2 and PO_3 corresponding reflected rays O_2D and O_3E.

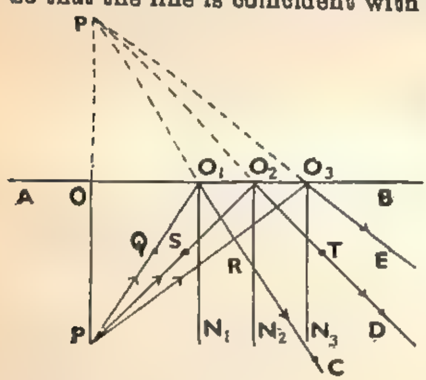


Fig. 146

Draw normals O_1N_1, O_2N_2 and O_3N_3 at points O_1, O_2 and O_3. Produce lines CO_1, DO_2 and EO_3 backwards to meet at point P_1 behind the mirror. Join PP_1 by the straight line meeting AB at point O.

* The imaginary plane at a depth of two-thirds the thickness of the mirror is the image of the back surface for nearly normal incidence of light.

Results—Measure the angle P_1OB with a protractor which ought to be $90°$.

No. of Reading	Length of OP in cm.	Length of OP_1 in cm.	Difference cm.
1.	8·2	...	0
2.	...	8·1	0·1
2.	8·2	...	...

Discussions—The accuracy of doing the experiment lies mostly with the accuracy with which the pins may be fixed along the image lines, and the object pin may be fixed vertical. The mirror should be silvered at the front face or else the line AB should be placed behind the front surface at a distance of two-thirds of the thickness of the mirror. Observations in fixing up the pins should be made as close to the plane of the paper as pos·ible, otherwise the line CO_1, DO_2 and EO_3 may not meet at the same point.

ORAL QUESTIONS

What are the laws of reflection? What is the defect if a thick mirror is used or the mirror used is not plane? Why is it that all the pins should be fixed as vertically as possible? Would the accuracy of the experiment increase or decrease if the pins are very thick? Would there be any advantage if the pins are blackened or glazed? What is the nature of the image of a plane mirror? What is the difference between a real and a virtual image? Is it possible to get a real image in a plane mirror? How can you check the thickness of a plane mirror or its planeness?

Effects of Refraction in a Thick Mirror—If a sheet of thick glass plate be silvered at the back surface, then a beam of light on being incident on the mirror is partly reflected from the front surface due to which an image is formed. Another part of the incident beam, which is refracted into the body of the glass, is reflected from the silvered surface and is finally emergent into air. A more prominent image is formed due to this beam. As a re-ult, two images of an object is seen, when looked obliquely. But when viewed almost normal to the mirror, the first image becomes very faint owing to poor reflecting power of the glass for normal incidence. Our attention is prominently drawn to the other image, which is due to reflected rays from the silvered surface. Let AB represent the back surface of a thick glass mirror of thickness SV = T, say, (Fig. 147). A ray of light MN on being incident at the front surface QN is refracted along NP and being reflected from the silvered surface AB is finally emergent along QR. If the incident and reflected rays are traced backwards, they meet at O on a dotted plane CD which appears to serve as the reflecting plane for these rays. For *nearly normal incidence* of rays and taking the refractive index of glass to be 1·5 the distance of this plane from the front surface is two-thirds of the real thickness of the mirror. But as the obliquity of the

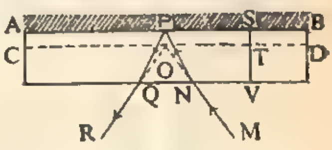


Fig. 147

incident beam increases, the virtual reflecting plane OD recedes from AB. Consequently for a thick mirror and for various angles of incidence, the plane OD is not a fixed one. (Vide Basu & Chatterjee's Intermediate Physics : Light : Chap. IV).

Method of Parallax

Parallax is the apparent change of relative position of two objects or an object and an image. If there are two objects A and B along the line of sight in the direction E_2A it is possible to ascertain which one is nearer by looking at them from a different direction. By observing along the direction E_3A it would appear that B is to the right of the line of sight (Fig. 148). If, on the other hand, A is seen in the direction E_1A, B will appear to move to the left of the line of sight. Thus the more distant object moves in the same direction as the moving eye relative to the nearer object. The method is practically utilized in locating the position of the image in some experiments on light.

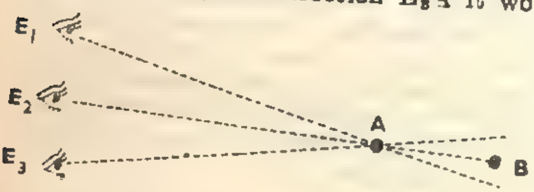


Fig. 148

Date—

EXPERIMENT 82

To Determine the Position of the Image By Parallax Method

Theory—The image of an object due to a plane mirror is formed as far behind the mirror as the object is in front of it. If a second object of identical appearance is fixed up at a position behind the mirror such that there is no parallax between it and the image of the first pin, then the position of this object determines the position of the image.

Apparatus—Drawing board, a plane mirror mounted vertically, drawing paper, scale, some fixing pins, two long hair pins.

Procedure—Fix a drawing paper on the board and place the

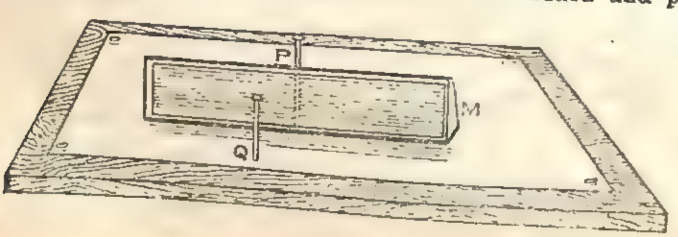


Fig. 149

plane mirror vertically on it. Draw the edge of the reflecting surface of the mirror with a pencil. (Fig. 149).

Fix a hair pin Q vertically a few inches in front of the mirror. The length of the pin must be greater than the height of the mirror strip Its image is now clearly seen in the mirror.

Take another hair pin of the same length and fix it up vertically on the board behind the mirror at any point along the line joining the first pin and its image. Now take an observation from such a direction that you clearly see a part of the image of the first pin and the upper part of the second pin. Then slowly move your head side to side and observe the relative shift of position of these two. If you see that second pin is having smaller movement than the image of the first pin, the second pin is to be brought nearer the mirror. But if the case is otherwise, the pin is to be shifted away along the line joining the first pin and its image. By repeated trials fix the pin at such a position behind the mirror that the part of this pin projected above the mirror appears to be the continuation of the image of the first pin and moreover there would be no relative shift of positions of the image and the projected part of the pin wherever eye is placed. The position of the second pin is the position of the image due to the first pin.

Remove the mirror and the pins and join the two pin pricks by the straight line cutting the outline of the mirror as a certain point. Measure the distances of the two pricks from the line of section of the mirror. Repeat the observation at least three times for three different positions of the pin

Results—

No. of Readings	Object distance	Image distance	Difference	Angle between PQ and AB	Difference from a Rt. Angle
	cm.	cm.	cm.	Deg	Deg.
1.	8 2	8·2	0	89·5	0·5
2.	...	10·4	0·1	89 0	1 0
3.	6·4	...	0	90 0	0
4.	...	12 6	...	..	0·5

Discussions—To get a distinct vision of the image of the pin, the eye should be placed properly. The height of the pins should be greater than height of the mirror for viewing parallax. Virtual images should always be located by the parallax method.

ORAL QUESTIONS

What is parallax? How to apply this method? In a parallax method how do you know which one is nearer or more distant? Why is the line drawn on the board made coincident with the silvered surface and not with the front surface? You are supplied with a thick and a thin plane mirror: which one would give you better results and why?

Refraction of Light

When a ray of light passes from one medium into another, the ray generally undergoes a change of direction at the surface of separation of the two media This is called the *refraction* of light.

The angle between the incident ray and the normal at the point of incidence is called the *angle of incidence*. The angle between the

refracted ray and the normal is called the *angle of refraction.* The ratio of the sine of the angle of incidence to the sine of the angle of refraction is called the *refractive index* of the second medium with respect to the first. This ratio is a pure number which depends upon the nature of the media in contact and the colour of the incident light. Thus, if i be the angle of incidence of a particular colour of light in a medium b and r be the corresponding angle of refraction in another medium c in contact, then, $\frac{\sin i}{\sin r} = {}_b\mu_c$

It has been found by actual measurement that this number also represents the ratio of the velocity of light in the first medium to the velocity of light in the second medium. Since the refractive indices of transparent solids and liquids are always greater than unity, it follows that velocity of light in air is greater than that in a solid or liquid.

Date—

EXPERIMENT 83

To verify the Laws of Refraction and to determine the Refractive Index of a Plane Parallel slab of Glass

Theory—The following are two laws of refraction :—

(1) The incident ray, the normal at the point of incidence and the refracted ray lie in one plane.

(2) The sine of the angle of incidence bears to the sine of the angle of refraction a constant ratio depending upon the nature of the two media in contact and the colour of light.

This constant ratio is called the refractive index of one medium with respect to the other for a given colour of light.

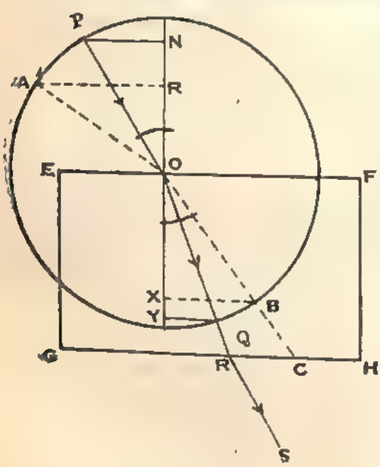


Fig. 150

Apparatus—A rectangular block of glass, drawing board and paper, fixing and hair pins, a compass, protractor and a scale.

Procedure—Fix the drawing paper on the board and place the glass block at the middle part of the paper (Fig. 150). Draw an outline of it, say EFHG with a fine pencil (Fig. 150). Fix two hair pins at P and O vertically on the board so that the line joining P and O is oblique with respect to the block and at a distance of about 10 cm. from it. The pin at O may conveniently be fixed in contact with the glass block. Now look from the opposite side of the block and fix a third pin R. Remove the pin at P to some other point A and taking out the pin at R fix it in contact with the glass face at some other position C such that the pins appear to be in one straight line. Put numbers 2 and 2 at A and C. In a similar

way draw four or five incident rays at various angles and corresponding refracted rays and insert always same numbers for the upper and the lower pin positions. Remove the glass block and join all pin-prick positions to the point O. The line O to 1 (position P) is the incident ray and the line O to 1 (position R) is the corresponding refracted ray. So numbers 2, 2 and 3, 3 etc., give corresponding pairs of rays. Draw a perpendicular XN at O and measure with a protractor all the angles of incidence with corresponding angles of refraction. Tabulate the results as shown.

Results —Verification with a protractor:

No. of Readings	Angle of incidence Deg.	Sine of angle i	Angle of refraction Deg.	Sine of angle r	$\frac{\sin i}{\sin r}$	Mean
1	25	0·42	16	0·27	1·5	
2	36	0·59	...	0·39	1·5	1·5
3	...	...	...	...	...	

Geometrical verification ;

Draw a circle with O as centre cutting the incident rays at points A P, etc. and refracted rays at points B Q, etc. From points A P BQ etc. draw perpendiculars PM, PN, BY, QX, etc. on the normal NOX.

Then $\frac{\sin PON}{\sin QOX}=\frac{PN/OP}{XO/QN}=\frac{PN}{QY}$

and similarly $\frac{\sin AOR}{\sin BXY}=\frac{AR/AO}{BX/BO}=\frac{AR}{BX}$

Now measure the lengths of the perpendiculars with a divider and a diagonal scale and find the corresponding ratios which give the value of the refractive index.

No. of Readings	Length of perpendicular in air cm.	Length of perp. in glass cm.	The ratio of the perps.	Mean value of ratio
1	1·8	1·2	1·5	
2	...	1·9	1·5	
3	3·6	...	...	1·5
4	...	2·4	...	
5	...	1·5	1·5	

Discussions—The angles of incidence and refraction should not be taken too small as otherwise percentage of error in measuring such angles would be large. An angle can be measured with a protractor correct to the nearest degree, and consequently its sine should be expressed correct to two decimal places. Hence the value of refractive index should be calculated correct to one decimal

place only. But using a divider a length can be measured more conveniently correct to a milimetre. Hence by the geometrical method the value of refractive index comes out correct also to one decimal place.

The angles of incidence should be measured almost at equal steps from 0° to 90° and a graph may be drawn with the angle of incidence as abscissa and corresponding angle of refraction as ordinate. The nature of graph is shown in Fig. 151. The value of the angle of refraction corresponding to the angle of incidence of 90° represents the critical angle for the medium.

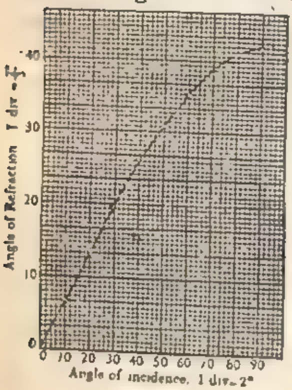


Fig. 151

Lateral Deviation of Transmitted rays—If the glass slab is plane parallel then the incident and the emergent rays are also parallel. But except for normal incidence, there is always a lateral deviation of the emergent ray with respect to the incident. This lateral deviation increases with the angle of incidence.

Denoting the angle of incidence by i and the lateral deviation by δ, we can get a series of values of i by taking readings at various angles of incidence and correspondingly there would be a series of values of δ. Then a graph may be plotted with i as the abscissa and δ as ordinate.

ORAL QUESTIONS

What are the laws of refraction of light? What is meant by refractive index? How is the velocity of light connected with the refractive index? Has refractive index any bearing on the colour or wave length of light? If so, you are measuring refractive index for which colour? A light ray moves from air to glass; in which direction does it bend? What is critical reflaction and how does it occur? What is meant by lateral deviation through a glass block? Does lateral deviation depend upon the angle of incidence or thickness? If so, how?

Object in a Denser medium

If an object, placed within an optically denser transparent medium, be viewed from air in a vertical direction, it appears to be partially raised. The refractive index of the medium is then given by the ratio of the real depth of the object below the surface of separation to its apparent depth The proof is given below,

Let OPRQ be a part of a transparent medium of refractive index μ having parallel faces OP and QR (Fig. 152) The medium may be a solid slab such as a piece of glass or some quantity of a liquid kept in a vessel Let A be a point source of light at the bottom of such a medium. To find the position of the image of A when viewed

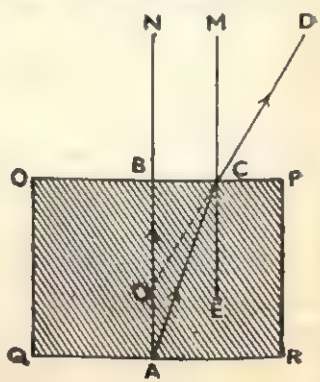


Fig. 152

from air *in a vertical direction* we make the following geometrical construction.

Draw a line AB at right angles to OP to a represent a ray of light travelling in a vertical direction. The ray passes out into air undeviated in the direction BN. Draw another ray AC at a very small inclination with the normal MCS. Let the refracted ray in air be CD. It is to be noticed that the two rays BN and CD passing out in air are divergent so as not so meet actually. Produce CD *backwards* to meet BA and O. The point O is then the position of the virtual image of A.

By construction $\angle MCD = BOC$
$\angle ACS = BAC$

$$\therefore \quad \mu = \frac{\sin \angle MCD}{\sin \angle ACS} = \frac{\sin \angle BOC}{\sin \angle BAC} = \frac{BC/CO}{BC/CA} = \frac{CA}{CO}$$

If the point C is very near to B then $CA = BA$ and $CO = BO$.

Hence $\mu = \frac{BA}{BO} = \frac{\text{Real depth}}{\text{Apparent depth}}$

The expression holds only for a narrow pencil of light travelling vertically from a point source in the denser medium.

Date—

Experiment 84

To Determine the Refractive Index of a Glass slab by Parallax method

Theory—A point object in contact with the base of the glass cube appears to be raised when viewed normally. The refractive index of glass μ is then given by the expression.—

$$\mu = \frac{\text{Real thickness of the glass slab}}{\text{Apparent depth of the point object}}$$

Apparatus—A glass cube, a drawing board and paper, a divider and metre scale, a long pin and holder.

Procedure—Mark a cross with ink on the drawing paper fixed on the board. Place the glass cube on the board in such a way that one of its edges is in contact with the junction of the cross at A (Fig. 153). Observe vertically along this edge of the cube as shown in the figure. One half of the cross which remains outside the glass cube gives the actual position of the cross while its other half which is just under the glass appears to be raised by refraction. Fix a pin in a horizontal position upon an adjustable vertical stand and place the point of the pin in contact with the vertical edge in a line with the observed image. Now gradually raise it from the

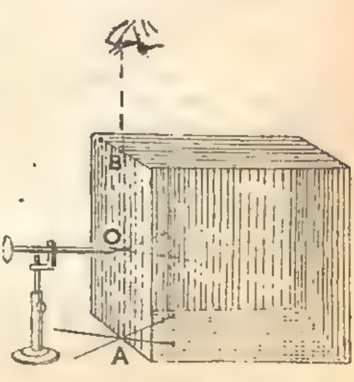


Fig. 153

bottom and move the eye slightly to-and-fro until the parallax between the pin point and the image of the cross is removed at some point O. Then the image of A is at O. Measure very accurately with a metre scale or otherwise the distance between the pin point O and the upper edge of the glass cube B vertically above the point A. Raise the pin a little distance above and gradually lower it with the eye slightly moving to-and-fro until at a certain level parallax has been removed between the pin point and junction of the cross as seen by refraction. Again measure the distance OB. In this way by lowering and raising the pin, take four or five readings of OB. Finally measure the thickness or height of the slab an equal number of times and tabulate the readings. The ratio of real to apparent depth gives the refractive index. The mean value of the ratio gives the mean refractive index.

Results—

No. of Readings	Real Depth AB cm.	Apparent Depth OB cm.	$\mu=\frac{AB}{OB}$	Mean Ref. Index
1	8·0	5·4	1·5	
2	...	...	...	
3	8·0	...	...	1·5
4	...	...	...	
5	...	1·5	1·5	

Discussions—Different samples of ordinary glass have got different refractive indices ranging from 1·5 to 1·54. Although observation is made in white light the effect of dispersion is negligbly small. What we get is the mean refractive index of the colours. In avoiding parallax the eye should not be moved too much, as then the coincidence of the pin point with the image cannot be obtained for all positions. This is due to a phenomenon known at *spherical aberration.*

Oral Questions

What do you mean by refractive index of a substance? Does it vary with different substances? Why do you look vertically to see the image? Suppose that you look obliquely into the glass slab, would the image rise or go down? What is the nature of the image that you see within the glass slab? What is parallax and why do you avoid parallax error in this experiment? Will the apparent depth of the image change on changing the nature of refracting medium? What would happen to the image within the glass cube, if you look vertically from within water.

Date—

Experiment 85

To Determine the Refractive Index of a Liquid with a Vernier Microscope

Theory—If a point object at a depth h below the surface of the liquid be viewed normally, it appears to be at an apparent depth x. The refractive index μ of the liquid is then given by the ratio h to

x. Let the actual reading of the vernier microscope when focussed for the point object be d_1 and the reading for its image within the liquid be d_2. Let the reading for the surface of the liquid be d_3.

Then the refractive index $\mu = \dfrac{d_3 - d_1}{d_3 - d_2}$

Apparatus—A small glass cubical vessel, some liquid (water) and a vernier microscope.

A vernier microscope consists of a microscope M capable of sliding along a vertical scale S_1 by a rack and pinion arrangement R_1 (Fig. 154). A vernier scale V_1 slides with the microscope and serves to determine its position accurately. The vertical scale with the microscope can move about within a groove on a stage B being worked by another screw arrangement R_2. On the stage just at the border of the groove there is a similar scale S_2. The movable base of the microscope is provided with another vernier V_2. The stage is mounted upon levelling screws LL and is provided with a circular spirit level C. Such a microscope when focussed upon a surface placed on the stage gives always a constant reading on the vertical scale.

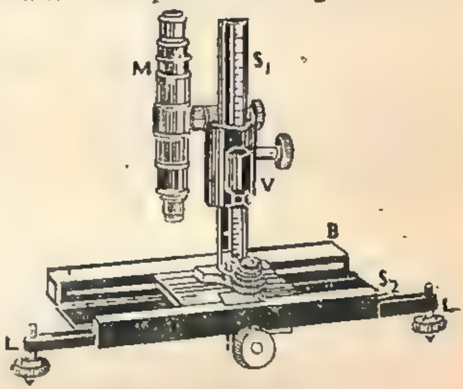


Fig. 154—Vernier Microscope

Procedure—With the help of the base screws, bring the *bubble* of the spirit level of the stage of the microscope at its centre. If the microscope is not provided with a spirit level, ask for a spirit level and place it on the stage and then level the stage with the base screws. When the stage has been levelled, the microscope stand becomes vertical. In its usual position, the axis of the microscope is then vertical. Now look through the eye-piece. If the crosswire or a micrometer scale is not clearly visible, draw in or out the eye-piece until it is most distint in the field of view Place the glass vessel B upon the stage A under the microscope. (Fig. 155). By rotating the adjustable screw R_1 focus any mark preferably a scratch mark on the inside surface

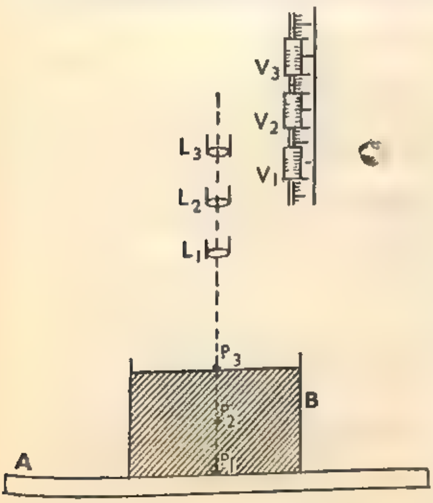


Fig. 155

of the vessel. Let the position of the microscope objective be at L_1 and that of the vernier at V_1 when the scratch is accurately focussed. Take the reading of the vernier and call it the first reading. Then slightly move the screw and focus the scratch again and take the venier reading. In this way take three readings of the vernier for the scratch position. Pour some quantity of liquid into the vessel without disturbing its positions such that the level of the liquid does not touch the microscope objective. Raise the microscope through a suitable distance and focus the image of the scratch again which is at some point P_2 within the liquid. The position of microscope objective is at L_2 and the corresponding vernier position is V_2. Take the reading of the vernier three times each time focussing this image; let this be the second reading. Now, scatter some cork powder on the surface of the liquid and raise the microscope still farther to focus the grains of powder floating on the surface of the liquid. Let the position of the objective be L_3, and the corresponding position of the vernier be V_3. Take the reading of the vernier three times. each time focussing the grains; let this be the third reading. In each position of the microscope take reading avoiding back-lash error and parallax. Then the real thickness of the liquid is the difference of third and first readings and the apparent depth of the image in the difference of third and second readings.

$$\therefore \quad \mu = \frac{\text{3rd reading} - \text{1st reading}}{\text{3rd reading} - \text{2nd reading}}$$

If time is a avaiable, take a different quantity of the same liquid and tabulate another set of readings.

Results—(Typical)

Liquid supplied is cedar wood oil.

50 divisions of vernier scale = 49 divisions of main scale

$$\therefore \quad \text{Vernier constant} = \frac{1}{50} \text{ of main scale.}$$

Smallest division of the main scale = 0·5 mm.

$$\therefore \quad \text{Vernier constant} = \frac{0·5}{50} \text{ mm.} = 0·001 \text{ cm}$$

(1) First Reading (Position of the Scratch)

No. of Readings	Main Scale cm.	Ver. Scale cm.	Total cm	Mean cm.
1	9·6	21 × 001	9·621	
2	9·6	22 × 001	...	9·621
3	...	21 + 001	...	

(2) Second Reading (Position of image of scratch) = 10·211 cm.
[Make a similar tabulation for (2) and (3)

$$\therefore \quad \mu = \frac{\text{3rd Reading} - \text{1st Reading}}{\text{3rd Reading} - \text{2nd Reading}} = \frac{1·731}{1·141} = 1·516$$

Discussions—The least count of the vernier of the microscope is generally 0·001 cm. Hence we may get a reading accurate upto the 3rd place of decimals. The value of refractive index. as determined by this method, is correct upto the third place of decimals. This is, therefore, a very accurate method of measuring refractive index of a solid slab or liquid.

ORAL QUESTIONS

What is refractive index? Has refractive index any relation with the velocity of light in the medium? What is the advantage of using a vernier microscope? Does it offer any greater accuracy, if so how? Why do you level the microscope stage? Why is the microscope kept vertically? What is the effect on the position of the image, if the microscope is kept inclined?

Date—

EXPERIMENT 86

To Measure the Refractive Index of a Liquid by Concave Mirror method

Theory— If a small object be placed above a concave mirror containing some liquid in such a way that the image of the object is formed at the same position as the object itself, then the refractive index of the liquid is given by the ratio of the vertical height of its centre of curvature and the height of the object both measured from the liquid level.

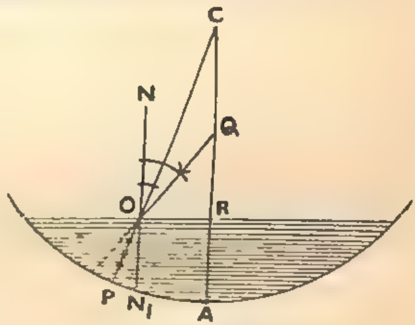


Fig. 156

The proof of this can be given with reference to Fig. 156 in which the circular arc represents the section of the mirror, C the centre of curvature of the mirror and AC the principal axis. Q is a point source of light such that the image of Q is at the same position when the mirror is partly filled with water. Take a ray of light QO incident on the surface of liquid. This ray after refraction will take a path OP. In order that the image may be formed at Q the refracted ray OP after reflection from the concave mirror retraces its path. Therefore PO if produced would pass through the centre of curvature of the mirror. At O a normal NON_1 is drawn. Then angle of incidence QON = OQR.

Angle of refraction PON_1 = OCR

$$\therefore \quad \mu = \frac{\sin OQR}{\sin OCR} = \frac{OR/OQ}{OR/OC} = \frac{OC}{OQ}$$

If the mirror is of small aperture, then $\dfrac{OC}{CQ} = \dfrac{CR}{QR}$

Apparatus—A small concave mirror, tripod stand, a hair pin and a vertical stand.

Procedure—The mirror is placed on a tripod stand with its face upwards. The pin is held horizontally on a vertical stand and adjusted to such a height that the image of the pin is on the pin. The pin is then at the centre of curvature of the mirror. Some quantity of liquid is then poured on the mirror and the vertical height of the pin above the free surface of the liquid is measured with a metre scale. Let it be h_2.

When liquid is poured on the mirror, it is found that the image position due to the combination of the liquid and the mirror is changed. Pin is now gradually lowered until the image coincides again with the object. The position of the coincidence is examined by the method of parallax. A number of readings is taken and the height of the pin above the liquid surface is measured each time with a metre scale. Let this be h_1. Then the refractive index of the liquid is h_2/h_1.

Results—

No. of Readings	First position of the pin above liquid level $=h_2$ cm.	Second position of the pin above liquid level $=h_1$ cm.	Refractive index $=\frac{h_2}{h_1}$	Mean
1	13·5	10·1	1·33	
2	...	...	...	
3	...	...	...	1·33
4	...	...	...	
5	...	...	...	
			...	

Discussions—The expression for the refractive index is obtained in this case on the assumption that the aperture of the mirror is small. Hence the effective aperture of the mirror used should be made small by covering the face of the mirror with a piece of wood or some such opaque material having a central circular hole of about 2 inches in diameter. The object should be strongly illuminated.

Image by Oblique refraction at Plane Surface

It has already been pointed out on page 237 that the image of an object point, placed in a denser medium, when viewed normally to the refracting surface appears raised along the line of sight and that the ratio of the real to the apparent depth of the object is equal to the refractive index of the lower medium with respect to the upper. But this simple relation does not hold good when the point object is viewed in an *oblique direction*, as would be seen by the following consideration.

For simplicity assume that the point object is embeded in a medium of refractive index μ and the upper medium is air of

refractive index unity (Fig 157). Let the point object be at P from which a normal PO (Fig. 158) is drawn to the surface of

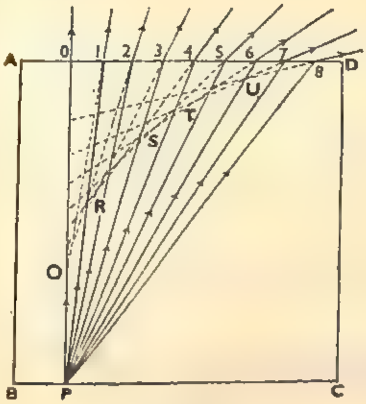


Fig. 157

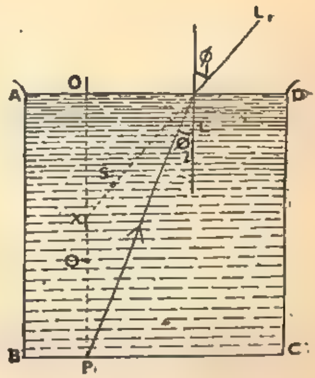


Fig. 158

separation AD. Take an oblique ray PL which meets at an angle ϕ_2 with the normal at L. Let the emergent ray LL_1 make an angle ϕ_1 with the normal. Produce L_1L to meet OP at X. It therefore follows that an eye placed at L_1 sees the image of P *some where* along the line LX. Actually the eye observes the image of P at some point S on LX such that a *small cone of* rays diverging from P and following the principal direction PL appears after refraction to proceed from that point.

The direction of the ray LL_1 corresponding to any ray PL can be found from the following principle. For refraction at L, since $\phi_1 = \angle OLB$.

$$\mu = \frac{\sin \phi_1}{\sin \phi_2} = \frac{OL/LR}{OL/LP} = \frac{LP}{LR} \qquad \ldots \quad (i)$$

The equation affords a geometrical method of drawing the refracted ray in air corresponding to any incident ray in the lower medium of a *known* refractive index μ. Suppose that the lower medium is glass of refractive index 1·5 and upper medium is air ($\mu = 1$) and that OP = 10 cm.

Now from $\triangle POL. = \sqrt{PO^2 + OL^2} = \sqrt{100 + OL^2}$

and from $\triangle ROL$, $RL = \sqrt{RO^2 + OL^2} = PL/\mu = \cdot 66\ PL \qquad (iii)$

since $\mu = PL/QL = 1\cdot 5$

From equ. (ii), we can find PL for a known value of OL and from equ. (iii) we know the length RO by knowing PL. The following table gives various values of OL. PL and RO for OP = 10 cm. and $\mu = 1\cdot 5$.

Results—

Length OL cm.	Length PL cm.	Length RO cm.	Length OL cm.	Length PL cm.	Length RO cm.
0	10·0	6·66	5	11·18	5·42
1	10·05	6·60	6	11·7	3·18
2	10·20	6·50	7	12·2	3·93
3	10·44	6·20	8	12·3	2·71
4	10·80	5·87	9	13·4	imaginary

Prism

A prism is a part of a transparent medium bounded by two plane surface meeting at an angle. In Fig. 159, ADEC is one plane face of the prism and ADBF is the other plane face meeting along the line AD. The side ECEF opposite to the angle is called the *base* of the prism. The section of the prism by a plane at right angles to the edge AD is called the *principal plane* of the prism. The angle BAC in the principal plane of the prism is called the angle of the prism. Hence the section ABC as shown separately in Fig. 160 is the principal plane of the prism. Refraction through a prism is generally considered in its principal section.

Fig. 159 Fig. 160

A ray of light on being incident on any side of the prism would be refracted into it obeying the laws of refraction. The refracted ray of light within the prism on meeting the other face generally goes out into air unless critically reflected. The final ray from the prism into air is called the emergent ray.

Date—

Experiment 87

To Measure Deviation through a Prism and to Determine its refractive Index

Theory—The angle of deviation in a prism is the angle between the incident ray and the corresponding emergent ray.

The refractive index of the material of a prism for light of a given colour is the ratio of the sine of the angle of incidence to the sine of the angle of refraction for any ray of that colour at any point of the refracting side of the prism.

Apparatus—A glass prism, drawing board and paper, a few fixing pins and hair pins.

Procedure—Place the prism on its principal plane on the drawing paper in a manner as shown in Fig. 161, and draw an outline ABC of the prism with a fine pencil (Fig. 162). Fix two hair pins *vertically* on the paper, one close to refracting face (as shown by P) and the other at a distance of 6 to 10 cm. from it (as shown by R), in such a way that the line joining their feet in oblique to the face AB. Now look from the other refracting side of the prism keeping the eye as near to the plane of the paper as possible, and move your head sideways until the two pins appear to be in one line. Then fix up a third pin near the other refracting face (shown by

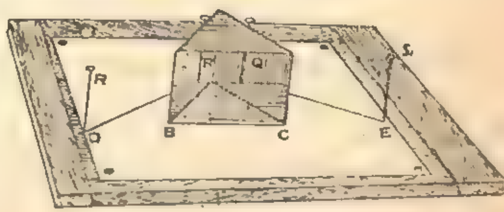


Fig. 161

Q) and a fourth pin at a convenient point S, such that the image of the first two pins and the other two pins appear to lie along the same straight line. Take out the prism and join the feet of the first two pins by a straight line RP to meet the edge at the point K. (Fig. 162). Similarly join the feet of two other pins by a straight line SQ to meet the other side at the point F. Join the point K and F by another straight line. Then RKFS is the path of the ray as it passes through the prism.

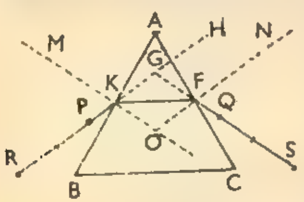


Fig. 162

Produce RP to any point H and SQ to meet at point G. The $\angle FGH$ between the two lines is called the angle of deviation ϕ. Draw a perpendicular MO at the point K on AB and another one NO at the point F. Then the angle of incidence i_1 is the angle RKM and the corresponding angle of refraction r_1 is the angle FKO. Replace the prism in the position ABC as accurately as possible and change the position of the pins at R and P, so as to change the obliquity of the incident ray. In a similar manner find the corresponding positions of the pins at Q and S. Thus measure i_2 and r_2. In this way take three sets of readings.

To find the refractive index of material of prism, measure angles

i_1, r_1, i_2, r_2 as accurately as possible with a protractor. Then from the table of sines find the values of sines of the corresponding angles. Then calculate the ratio of sin i_1 to sin r_1 and also of sin i_2 to sin r_2 in each case and obtain the mean value.

Results—

No. of Readings	First face		Second face				
	Angle of incidence i_1 Deg.	Angle of refraction r_1 Deg.	Angle of incidence i_2 Deg.	Angle of refraction r_2 Deg.	$\frac{\sin i_1}{\sin r_1} = \mu$	$\frac{\sin i_2}{\sin r_2} = \mu$	Mean μ
1	44	26	57	33	$\frac{67}{44} = 1{\cdot}5$	$\frac{48}{56} = 1{\cdot}5$	
2	...	...	...	...	...	...	1·5
3	...	...	...	...	...	...	

Discussions—The measurement of the angle with a protractor can be made with an accuracy of half a degree. Therefore the bigger is the angle the less is the percentage of error. But if i_1 is made greater than 50 or so then i_2 is found to diminish gradually if the material of the glass is crown. Therefore, the highest possible values for both i_1 and i_2 are near about 50° to which they should be set. An error of half a degree in measuring an angle of 50 entails an error of 1% in measuring the angle but 5% in measuring the sine of the angle so that the refractive index can be expressed correct to one decimal place.

Date—

EXPERIMENT 58

To Draw the Incidence Deviation Curve of a Prism

Theory—The graphical relation between the angle of incidence and the angle of deviation in a prism is nearly parabolic, the angle of deviation having a minimum value for some angle of incidence. If δ be the deviation corresponding to an angle of incidence and if α and i be the refracting angle and the angle of emergence. Then, $\delta = i - \alpha + \sin^{-1} [\sin \alpha \sqrt{\mu^2 - \sin^2 i} - \cos \alpha \sin i]$ showing the actual relation between δ and i.

Apparatus—Drawing board and paper, a few pins, a prism, a protractor and a drawing pencil.

Procedure—Place the prism on the drawing board and draw an outline of it ABC by a fine pencil. Remove the prism and take two points O_1 and O_2 on the line AB at some distance from each other and draw two normals O_1N_1 and O_2N_2 with a set square

(Fig. 163). Draw two angles $P_1O_1N_1$ and $P_2O_2N_2$ of values 45° and 60° with a protractor as accurately as possible. Now fix up two

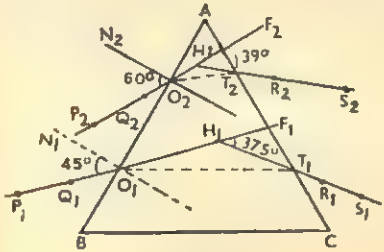


Fig. 163

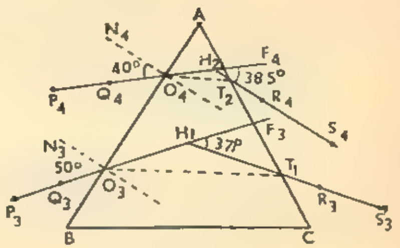


Fig. 164

pins vertically on the line P_1Q_1 and look through the other face AC. When P_1 and Q appear to be in one line, fix up two pins at R_1S_1 in

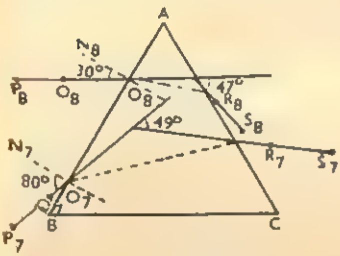


Fig. 165

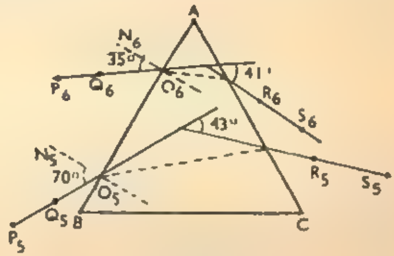


Fig. 166

a manner as explained in the preceding experiment. Then the line joining R_1 and S_1 is the emergent ray. Similarly find R_2S_2 corresponding to P_2Q_2. Produce lines P_1Q_1 and P_2Q_2 to some points F_1 and F_2 outside the triangle. Produce S_1R_1 and S_2R_2 to meet respectively P_1Q_1 and P_2Q_2 produced at H_1 and H_2 and measure the angles of deviation $F_1H_1T_1$ and $F_2H_2T_2$ between them with the protractor.

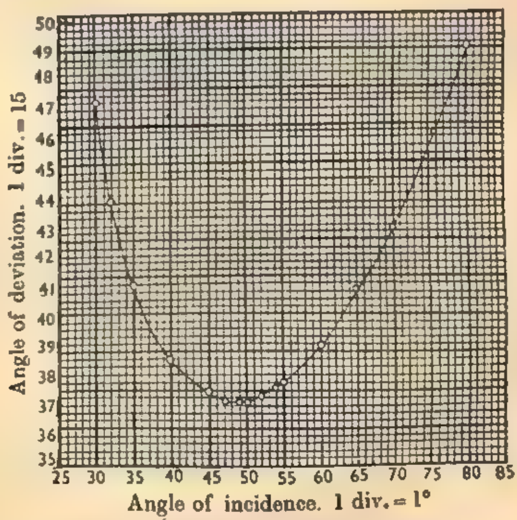


Fig. 167—Incidence Deviation Graph

Place the prism on a separate position on the drawing paper and according to directions already given find deviations for another two angles of incidence, say 40° and 50°. In this way find deviations corresponding to 8 or 10 angles of incidence ranging from 30° to 80° It is advisable for clear

diagrams to use one position of the prism on the drawing paper for two angles of incidence at a difference of 10° to 15°. If too many incident and refracted rays are drawn for one position of prism, the diagram becomes clumsy. Figs. 156 to 160 give four positions of the prism supplying eight readings. The graphical relation of i and δ is given in Fig. 167.

Results—

Angle of incidence	Angle of deviation	Angle of incidence	Angle of deviation
30°	47°	50°	37°
35°	41°	55°	37·5°
40°	39·5°	60°	39°
45°	37·5°	70°	43°

Discussions—On increasing the angle of incidence, the angle of deviation decreases to a certain minimum after which it continuously increases. The minimum deviation occurs for some value of the angle of incidence between 45° to 55° depending on the nature of the material of the glass and on the refracting angle of the prism. Therefore to get an accurate graph near the bend, the angles of incidence between 45° to 55° should be taken at frequent intervals. As the measurement of angles with a protractor can be made to an accuracy of half a degree, this method of drawing the graph is only approximate. The refractive index of the material of the prism can be determined from a study of the minimum deviation of the prism.

Oral Questions

Define a prism. What is the deviation in a prism? Why is the deviation always towards the base of the prism? What is the minimum deviation of a prism? What is the angle of a prism? What is the relation between the angle of the prism, the minimum deviation and refractive index? If a beam of white light is passed through a prism what is the effect on the transmitted beam? Why a coloured spectrum is not formed if sodium light is used as a source?

Determination of Angle of the Prism

The simplest way of measuring the refracting angle of a prism is to place the prism on a piece of drawing paper in its principal section and draw its outline with a fine pencil. The figure is evidently a triangle and the refracting angle of the prism corresponds to one of the angles of the triangle. This can be measured directly with a protractor.

There is an optical method of measuring the angle of the prism. The prism is placed as usual on the drawing board and its outline ABC is traced with a fine pencil point (Fig. 168). Two parallel lines are drawn to meet the sides AB and AC which are refracting edges. Four hair pins are fixed vertically at points P, Q, R and S on parallel lines. With the prism in usual position observation is made from the side AB so that the pins at P and Q appear by reflection from the face AB to be in one straight line. Keeping eye in this position two other hair pins are fixed vertically at P_1 Q_1 till all the four pins at points P, Q, P_1 and Q_1 appear to be in one straight line. In a similar way two other hair pins are fixed at R and S_1 when pins at R and S appear to be in one straight line by reflection from the face AC.

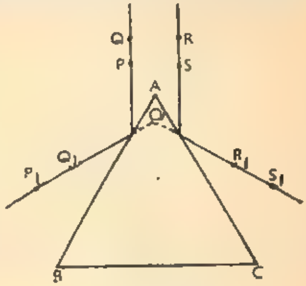


Fig 168

Two straight lines are made to pass through P_1Q_1, and R_1S_1 to meet at a point O. The angle P_1OS_1 is measured with a protractor. This angle is twice the angle of the prism (vide Basu and Chatterjee's Intermediate Physics, Light, Chapter VII). The angle to be measured in this case being double the refracting angle of prism, the percentage of error should be half.

Refractive Index and Minimum Deviation

We know that the refractive index μ of a prism is connected with the minimum deviation δ_m and the refracting angle of the prism α by the following expression,—

$$\mu = \frac{\sin\left(\frac{\alpha+\delta_m}{2}\right)}{\sin\frac{\alpha}{2}}$$

Hence if δ_m and α are determined experimentally, μ can be calculated. With reference to the section BAC of the prism in Experiment 67 it is found by actual measurement that the angle BAC is 60°. Again referring to the $i-\delta$ curve (Fig. 167) it is to be found that the minimum deviation is 37°.

$$\mu = \frac{\sin\frac{60^\circ+37^\circ}{2}}{\sin\frac{60^\circ}{2}} = \frac{\sin 48{\cdot}5^\circ}{\sin 30} = \frac{{\cdot}749}{{\cdot}5} = 1{\cdot}50$$

Since we can measure angles with a protractor with an accuracy of 0·5°, the value of μ should not be calculated to more than *two places* of decimals. Different samples of crown glass have got

different refractive indices ranging from 1·50 to 1·54. Flint glass prisms have got higher refractive indices.

Symmetricity at the Minimum Deviation

In connection with the incidence-deviation relation of a prism it has already been stated (vide Expt. 87) that there is a minimum deviation position of the prism. At this position the angle of incidence becomes equal to the angle of emergence, (For theoretical proof vide Basu and Chatterjee's Intermediate Physics—Light.)

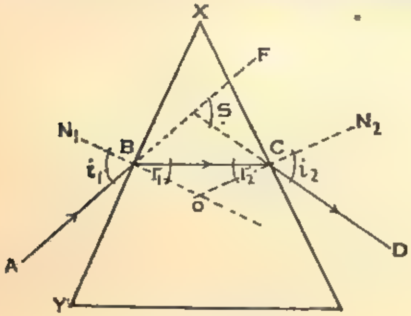


Fig. 169

Let a ray of light ABCD traverse the prism at the position of minimum deviation (Fig. 169). Then the angle of incidence i_1 is equal to the angle of emergence i_2. Since r_1 and r_2 are corresponding angles of refraction, $r_1 = r_2$.

Since ON_1 and ON_2 are normals to the two surfaces, $\angle OBX = \angle OCX =$ rt. $\angle$.

Hence $\angle OBX - \angle r_1 = \angle OCX - \angle r_2 \quad \therefore \quad \angle XBC = \angle XCB$ or $XB = XC$.

Therefore the ray within the prism passes *symmetrically* at the two sides in the position of minimum deviation.

Date—

EXPERIMENT 89

Symmetrical Method of Measuring Minimum Deviation and hence to find the Refractive Index

Theory—In the minimum deviation position of a prism, the ray within the prism passes symmetrically with respect to the refracting sides. Hence knowing δ_m and angle of the prism α, the refractive index of the prism can be found from the formula,—

$$\mu = \sin\frac{\alpha + \delta_m}{2} \Big/ \sin\frac{\alpha}{2}$$

Apparatus—A prism, 4 hair pins, drawing paper, protractor and divider.

Procedure—Place the prism on the drawing paper and draw an outline of it ABC on the paper (Fig. 170). Placing one point of the divider on the vertex A, mark off equal distance AQ and AR on the two edges.

Fix one pin vertically at Q and the other at R. Now look from one side to view Q and R, and put a third pin at P such that all the three appear along one line. Again look from the direction PQ and fix a fourth pin at S to appear along the same line.

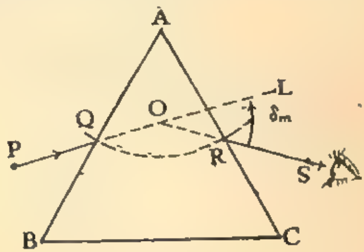


Fig. 171

Join PQ and produce it to a point L and produce SR to meet the line at O. Measure the angle LOS with the protractor which gives δ_m. Take three or four such equal lengths at different regions on the edges and measure δ_m from each set.

To measure the refracting angle of the prism, measure directly the angle at A with a protractor or more accurately by the pin method already described on page 249.

Results—

Angle of minimum deviation :

(i) 38° (ii) 38.5° (iii) 38.5° (iv) 38° $\therefore$ mean $= 38.25^\circ = \delta_m$.

Refracting by pin method :

(i) $121^\circ/2$ (ii) $120.5^\circ/2$ (iii) $121^\circ/2$ $\therefore$ mean $= 60.5^\circ$.

$$\text{Hence } \mu = \frac{\sin 39.4^\circ}{\sin 30.25^\circ} = \frac{.7593}{.5040} = 1.50$$

Discusions—This is the simplest method of finding the minimum deviation ray through a prism. The accuracy of the reading lies in having equal intercepts along the two edges AB and AC of the prism. The determination of angle of the prism by the pin method, when accurately set, should give better results than by measuring it directly.

EXPERIMENT 90

Date—

Rotation Method of Determining Minimum Deviation Position of a Prism

(Hence to show $i_1 = i_2$ and to find δ_m and μ.)

Theory—Near the the position of minimum diviation of a prism the rate of change of deviation with a change of the angle of incidence is very small and sensibly equal on either side of the exact point of minimum deviation.

Apparatus—A prism, a piece of thick paper, four pins and drawing materials.

Procedure—Out of the thick paper supplied out off a piece as shown in Fig. 171, big enough for the given prism to be placed in

its principal section ABC. Fold one of the pointed ends, say D, at right angles into the position D_1 serving as a handle to rotate the paper. The other pointed end E serves as the pointer to measure the rotation.

Place the paper upon a drawing board and fix a pin at P on the hump H so that the piece can freely rotate about this point as pivot. Place the prism symmetrically on the paper with its refracting angle

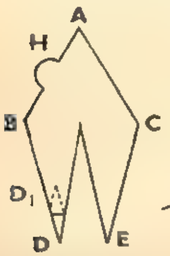


Fig. 172

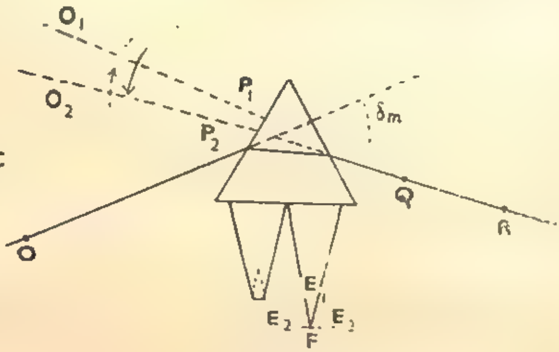


Fig. 173

coinciding with A (Fig. 172). Fix another pin at O on the drawing board at a distance of 10 to 15 cm. from P and look from the face AC till the two pins appear to be in one line in a direction such as P_1O_1. The angle between OP and O_1P_1 is angle of deviation for this particular position of the prism.

Now rotate the prism so as to cause the broken line to move to the left hand side of observer in a direction from O_1 to O_2 to decrease the angle of deviation. Continue the rotation slowly till the images of the pin appear to be stationary at some region and then *just* start to move towards the observer's side. Put a pencil mark against the pointer E in this position as at E_1.

Next *slowly* rotate the pointer in the opposite direction till the images being stationary for a little while *just* starts to move again towards the observer's right side. Put another pencil mark against the pointer E at E_2.

Bisect the distance E_1E_2 at some point F and place the pointer against this point. The prism is now in the position of minimum deviation. Put three dots corresponding to three vertices A, B and C. Now look along the direction OP and on the other side of the prism fix two other pins at Q and R at distance of 8 to 10 cm. along the same line of sight. Take out the prism.

Join the points OP by a straight line, and so also the points QR. Measure the angle between them with a protractor, which is δ_m. Take three observations at three different places on the board. The

angle of the prism may be measured directly with a protractor or by pin method. Draw normals at the points of incidence and measure angles of incidence and imergence.

Results—

No. of readings	Angle of minimum deviation $\delta°C$	Refracting angle of Prism α in °C	Angle of incidence i_1 in °C	Angle of emergence i_2 in °C	$\mu = \dfrac{\sin\frac{\alpha+\delta_m}{2}}{\sin\frac{\alpha}{2}}$	mean
1.						
2.						
3.						

Discussions—The pins should always be fixed vertically along the line of sight. The turning points of the images must be carefully noted since the accuracy in determining minimum deviation consists in fixing the pins at the turning points. Angles should be measured with a protractor, correct to half a degree.

Spectrometer

Experiments with prism by pin method cannot be done very accurately firstly because the direction of a ray is determined by fixing up pins, which are rather too thick and are subject to a parallax error ; secondly because the measurement of the angles is done with a protractor by which an utmost accuracy of half a degree or so may be claimed. Both these sources of errors have been reduced to a minimum in an apparatus called a spectrometer.

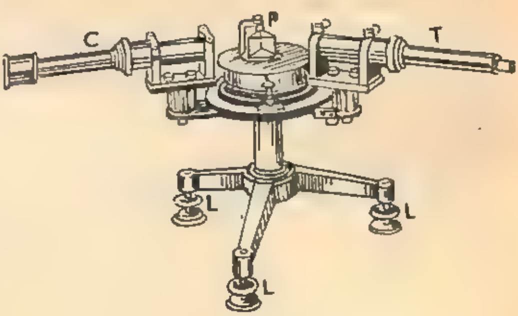


Fig. 174—Spectrometer

The apparatus consists of telescope T capable of revolving about a vertical axis and fixed upon a stand on three levelling screws L (Fig. 174) The eye-piece of the telescope is fitted with cross-wires on which an image of an object can very accurately be focussed. There is a turn table S which can also rotate on a vertical axis and it is called the prism table, on which the prism is kept. The prism table is also fitted with three levelling screws resting upon a platform. There is another attachment called the collimator, consisting of a metal tube carrying an achromatic convex lens at one side and an adjustable rectangular slit at its other end. There

is a fixed or movable circular disc graduated in degrees from 0° to 360°. The telescope as well as the prism table are provided with vernier scales sliding over the circular scale, so that any small rotations of any one of them can be accurately measured.

Date—

Experiment 91

To Measure the Refractive Index of the Material of a Prism with a Spectrometer

Theory—If α be the refracting angle of a prism, δ_m the minimum deviation and μ the refractive index of a prism then,

$$\mu = \frac{\sin\left(\frac{\alpha + \delta_m}{2}\right)}{\sin\frac{\alpha}{2}}$$

Apparatus—A spectrometer, prism, spirit level, a Bunsen burner sodium flame arrangement. (Description of a spectrometer should be given here.)

Procedure—Place a spirit level on the telescope tube parallel to its axis and for safety, tie the spirit level on the tube with a piece of thread. You would notice three levelling screws at the base of the instrument. Join up the base of the screws by straight lines marked with chalk or pencil to form a triangle. Mark the angular points of this triangle as 1, 2 and 3. Move the telescope until the axis of the telescope tube is parallel to the line joining any two levelling screws say, 1 and 2. If the air bubble of the spirit level is not at the centre, the telescope is not levelled properly in this position. Now bring the air bubble to the centre by working levelling screws 1 and 2. Then move the telescope through 180°, when the axis of the telescope becomes again parallel to the same line. The spirit level may not show in this new position that the telescope is levelled. Bring the bubble to the centre by moving it approximately half the distance by both the base screws 1 and 2 and other half by the levelling screw attached to the telescope. Again, bring the telescope back to the original position and see if it is still levelled. If not, level by means of screws 1 or 2 as was used initially. Again, move it through 180° and if still found out of level, repeat that half and half procedure to level it. Repeat this process of levelling over and over again until the telescope is levelled at these two positions only. When this is done, move the axis of the telescope through 90° and level it finally by the third base screw (No. 3). The telescope should hereafter show its levelling for all positions.

Now place the spirit level on the prism table with its axis parallel to a line joining the two levelling screws attached to the

prism table. Bring the bubble to the centre with both or either of the screws. Place the spirit level at right angles on the prism table to its former position and level it by the remaining screw attached to it. Thus the prism table is made horizontal.

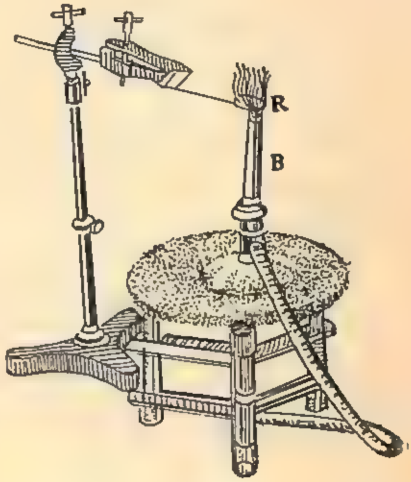


Fig. 175

Next, find the least count of the vernier attached to the telescope as well as the prism table. To do this place the vernier zero mark in coincidence with any main scale graduation at any part of the scale. Find how many divisions of the vernier scale are exactly equivalent to how many divisions of the main scale. Thence calculate the least count of the vernier. If $1/n$ main scale division be the least count of the vernier, then find the value of the main scale division, which might be any aliquot part of one degree, say $1/m$ degree. Then the vernier constant is $1/mn$ of a degree.

Turn the telescope towards a very distant bright object and adjust the eye-piece to get a very clear vision of the cross-wires, and then adjust the telescope to focus the image of the distant object on the cross-wires. In focussing the image there should be no parallax between the image and the cross wires. The telescope is thus focussed for parallel rays. Light up a Bunsen burner and place the flame behind the slit of the collimator. Fit up a wire ring wrapped up with asbestos fibre. Soak this ring with common salt solution and place it in the flame which is thereby coloured golden yellow. Look through the collimator lens and see whether the slit appears well illuminated. If not, open out the slit and adjust the position of the flame. The ring soaked in common salt solution and placed in the flame is shown in Fig. 175. Now turn the telescope in a line with the collimator so as to view the slit and adjust the collimator to get an well defined image of the slit on the cross-wires. If the image appears to be raised up or lowered in the field of view, turn the levelling screws attached to the collimator properly to centre the image. If the image is too wide make the slit narrow.

Place the prism on its principal section at the centre of the table and rotate the prism table slowly so as to increase the angle of incidence and follow the refracted image of the slit with naked eye. You would see that the image continuously moves in one direction, but from a certain position the image appears to turn back and reverse its course. Stop the rotation of the prism table *just when*

the image appears to turn back. The position of the prism, corresponding to the turning point of the image, is called the *minimum diviation position*. Bring the telescope to view the image and by small rotation bring the vertical cross-wire of the telescope to coincide accurately with the turning position of the image. If the image has got a breadth much greater than the wire, it is advisable to make the wire coincident with any edge of the image. Read the position of the vernier attached to the telescope. This corresponds to the reading of the image at the minimum deviation position.

Take out the prism without altering the position of the prism table and turn the telescope so as to view the direct image on the cross-wires, or preferably on any fixed edges of the slit. Read the vernier. This corresponds to the direct reading. The difference of these two readings gives the angle of minimum deviation.*

Place the prism again upon the table with the refracting angle facing the callimator (Fig. 176) and the refracting age coinciding with the centre of the prism table. The parallel beam of light is divided by the refracting edge into two halves and each half of the beam is reflected by each side of the prism. Slowly turn the telescope to view one reflected image to coincide with the vertical line of cross-wires and read the vernier. Again turn the telescope to view the other reflected image and make the vertical cross-wire coincident with the image of the slit. Read the position of the vernier. The difference of these two readings gives an angle which is double the refracting angle of the prism. In practice, take at least two readings for each position of the vernier by slightly altering the position of the telescope and bringing it again to the correct position, taking into consideration the backlask error of any screw. Reading of the minimum deviation may be taken on both the refracting sides of the prisms. Thus knowing $\propto$ and δ_m calculate the value of μ.

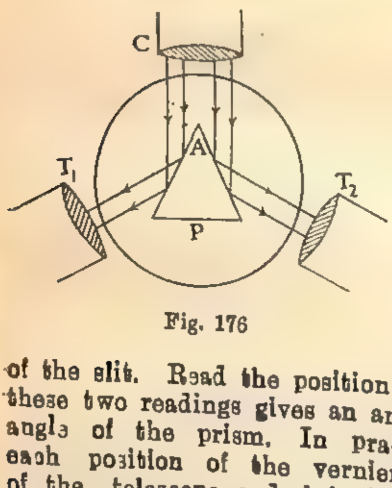


Fig. 176

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* The recording of direct reading just after the minimum deviation reading without altering the position of the prism table is necessary in cheaper types of spectrometers which have no fixed scales. The main scale is fixed with the prism table and verniers with the telescope. So the amount of rotation of the telescope is to be read while prism table is kept fixed. With such types of spectrometers, the angle of the prism may be read more conveniently before measuring the minimum deviation. This restriction is not imposed on spectrometers which have a fixed graduated scale and the telescope and prism table are provided with separate verniers.

Results—(Typical)

Determination of vernier constant of the telescope:

30 vernier division = 29 main scale divisions (suppose)

or, 1 vernier division = $\frac{29}{30}$ main scale division.

One main scale division = $\frac{1}{2}$ of a degree

$\therefore$ vernier constant = $1m - 1v = \frac{1}{30}m$

$= \frac{1}{30} \times \frac{1}{2}$ degree $= 1'$

Determination of Minimum Deviation :—(A typical set)

The scale readings are taken with one vernier only. If there are two verniers, then two tables may be made.

No. of obs.	Min. Dev. Reading		Direct Reading		Difference	Mean δ_m
	Main + vern.	Total	Main + vern.	Total		
1	162°15′+13′	162°28′	200°+6′	200°6′	37°38′	
2	162°15′+12′	162°27′	200°+6′	200°6′	37°37′	37°38′
3	162°15′+13′	162°28′	200°+6′	200°6′	37°38′	

Determination of Angle of the Prism :—

No. of obs.	Left-side Image		Right-side Image		Difference	Mean
	Main + vern.	Total	Main + vern.	Total		
1	139°30′+14′	139°44′	260°15′+6.5′	260°21·5′	120°37·5′	
2	139°30′+13′	139°43′	260°15′+6′	260°21′	120°38′	120°37′
3	139°30′+14′	139°44′	260°15′+4′	260°20′	120°36′	

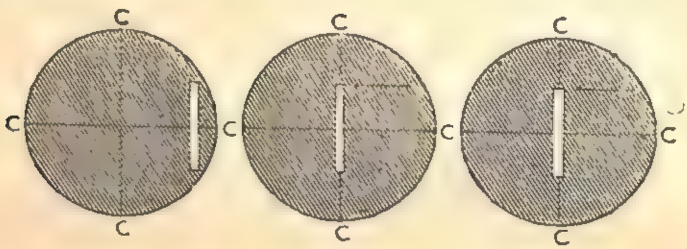
$$\text{Angle of the prism} = \frac{120°37'}{2} = 60°18'$$

$$\mu = \frac{\sin\frac{\alpha+\delta_m}{2}}{\sin\frac{\alpha}{2}} = \frac{\sin\frac{97°56'}{2}}{\sin\frac{60°18'}{2}} = \frac{\sin 48°58'}{\sin 30°9'} = \frac{\cdot 7544}{\cdot 5023} = 1{\cdot}502.$$

Discussions—In this experiment an angle can be measured with an accuracy of one minute and hence the sine of that angle may be found from the sine table (see the Table at the end of the Book) accurately upto the fourth decimal place Therefore, the value of the refractive index, as found by the experiment, is accurate at least upto three decimal places. The width of the image of the slit should be made very narrow so that the cross-wire may be accurately set. The collimator and the telescope should be adjusted for parallel rays to get the angle of incidence equal for each ray passing through the prism.

Schuster's Method of Focussing for Parallel Rays

Even without focussing a very distant object, the spectrometer may be adjusted for parallel rays by the Schuster's method in a dark room. To follow up the method the following procedure is adopted: Level the prism table, the telescope and the collimator with a spirit level as described on pp. 254. Light up a sodium flame before the collimator slit. Turning the telescope aside, look through the collimator lens with naked eyes and get the image of the slit. If the image is not obtained, the slit is closed and the slit is to be opened with attached screw. If the image is obtained, move your eyes from left to right from one edge of the collimator lens to the other edge and see whether the image is obtained clearly for



(a) (b) (c)

Fig. 177

all positions. If the image appears fainter as you turn to the right, the sodium flame is to be shifted slightly to the left and vice versa. When the image appears equally distinct for all positions, the flame has been placed co-axially. Place the prism on its principal section at the centre of the prism table with its base side either to the right or to the left, and search for the transmitted image of the slit. If the image is not obtained, slowly rotate the prism table towards the base side of the prism and try to follow up the image. When the turning point of the image is secured by one or two trials, keep the prism table fixed there. The position is evidently the minimum deviation position of the prism.

Turn the telescope so as to bring the minimum deviation image in the field of view. Keep the telescope fixed at an angle *slightly greater* than the minimum deviation angle, so that the minimum deviation image is seen *at an extreme position* of the field of view, as shown in (Fig. 177a). If the image appears too blurred or hazy, focus the telescope to make the image distinct. In whatever direction the prism table is rotated from the minimum deviation position, the image would be seen moving from its extreme position towards the centre of the field of view.

If the prism table is turned from its minimum deviation position so as *to increase the angle of incidence* of light, the image is found to *thin out gradually* as it moves towards the centre of the field of view

(Fig. 177*b*). The image at any such position is called the *slanting* image. Again, if the prism table is rotated from the minimum deviation position so as to *lessen the angle of incidence*, the image appears to *widen out* as it moves towards the centre; such an image is called the *normal* image (Fig. 177*c*).

Rotate the prism table so as to obtain the slanting image on the cross-wire of the telescope and focus the image with the telescope. Again rotate the table in the opposite direction to get the normal image on the cross-wires and focus the images by adjusting the collimator. In this way by alternately securing the slanting and normal images in the field of view, focus the images by telescope and collimator respectively. After a few adjustments both the images appear *equally distinct* when the spectrometer has been focussed for parallel rays.

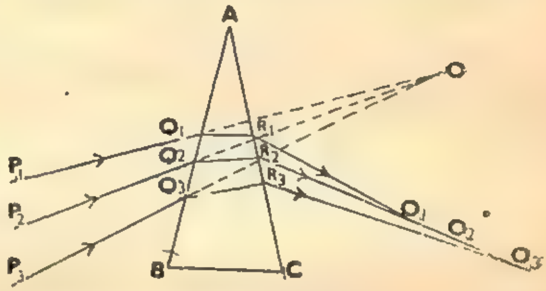


Fig. 178

Theory of Schuster's Method—In Fig. 178, a pencil of ray converging at a point O, is made to pass through a prism ABC in such a way that the mean ray $P_2Q_2O_2$ corresponds to the ray incident at the minimum deviation position of the prism. Now, by the virtue of convergence of the beam, the incident ray P_1Q_1 has its angle of incidence smaller than that of P_2Q_2 which is the minimum deviation ray. Hence for a small rotation of the prism so as to decrease the angle of incidence, the point O_1 at which the imergent rays R_1O_1 and R_2O_2 corresponding to P_1Q_1 and P_2Q_2 meet, would be the normal image. Conversely, the incident ray P_3Q_3 has got an angle of incidence greater than that of P_2Q_2. Hence the point O_3 where the corresponding emergent rays meet gives the slanting image when the prism slightly rotated in the opposite direction. It is to be noticed that the convergence of the emergent normal rays is always greater than that of slanting. Of the two beams, normal and slanting, when the telescope is adjusted to view the slanting image, it is focussed for a more parallel group of rays. When the normal image is brought into the field of view of a telescope already focussed for the previous slanting image, it appears blurred because a more convergent group of rays now enters the telescope. By this continued process of adjustment when both the images are equally distinct, rays coming to the telescope are rendered parallel and the purpose is finally achieved.

ORAL QUESTIONS

Describe the constituent parts of a spectrometer. Why it is called a spectrometer? What is the deviation through a prism? What is called the

minimum deviation position of a prism? Why do you set the prism at the minimum deviation position? Which method is preferable for refractive index measurement—pin method or spectrometer method and why? What are the other uses of a spectrometer? Why is it essential that the beam passing through the prism is to be made parallel? What are the normal and slanting positions of the prism? Explain Schuster's method of adjusting for parallel rays. What happens if in the the normal position of the prism telescope is focussed and in the slanting position collimator?

Critical Angle and Total Reflection

When a thin pencil of light, travelling in an *optically* denser medium, is incident at the surface of separation of a rarer medium, the refracted pencil is bent away from the normal drawn at the point of incidence; that is, the angle of refraction in the rarer medium is always larger than the angle of incidence in the denser medium.

Consider a ray of light P_1O travelling in glass to be incident at a small angle on the glass air surface. The refracted ray OQ_1 in air would naturally make a larger angle with the normal ON, by virtue of the law of refraction (Fig. 179). It follows then that if the angle of incidence is continuously increased a maximum value of this angle ($\angle P_2ON$) is obtained for which the angle of refraction in the rarer medium is 90°, that is the refracted pencil would graze the surface of separation of the media. If μ_2 be the refractive index of the denser medium and μ_1 that of the rarer medium, then this limiting value θ of the angle of incidence is obtained from the laws of refraction in the form,—

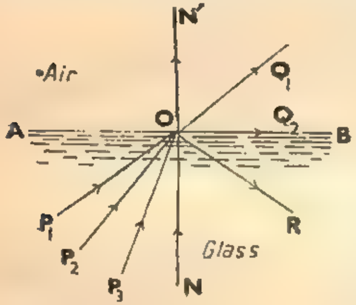


Fig. 179

$$\mu_2 \sin\theta = \mu_1 \sin 90° \qquad \text{whence} \qquad \sin\theta = \frac{\mu_1}{\mu_2}$$

Since μ_2 is to be larger than μ_1, the ratio of μ_1 to μ_2 is less than unity and θ would have a definite value less than 90° for a given pair of media and a given colour of light. Thus when a thin pencil of light proceeds from a denser to a rarer medium, the limiting value of the angle of incidence in the denser medium corresponding to which the refracted rays just grazes the surface of separation, is called the critical angle for the pair of media.

The refractive index of water is 1·33 and that of air is 1 very approximately. Hence the critical angle θ for water to air refraction is,

$$\sin\theta = \frac{1}{1\cdot33} = 0\cdot75 \qquad \text{whence} \qquad \theta = \sin^{-1} 0\cdot75 = 45°38'$$

In a similar way, it can be shown that the critical angle for crown glass to air refraction is nearly 40° and that for crown glass to water

is nearly 61°. When the angle of incidence in the denser medium be larger than the critical angle for the pair, no refraction is possible in the rarer medium and the incident ray is *totally reflected* in the denser medium according to the laws of reflection. This phenomenon is called **total reflection.**

Critical Reflection through a Combination of Parallel Plates

Let there be three plane parallel media of refractive indices μ_1, μ_2 and μ_3. Suppose that a ray of light in passing from the first to the second medium grazes the surface of separation of the second and the third media (Fig. 180). Then μ_3 must be less than μ_2. If θ be the angle of incidence at the second-third interface, then

$$\mu_2 \sin\theta = \mu_3 \sin 90^\circ = \mu_3$$

Again, if ϕ be the angle of incidence at the first-second interface, then also,

$$\mu_1 \sin\phi = \mu_2 \sin\theta$$

$$\text{or,}\quad \mu_1 \sin\phi = \mu_2 \sin\theta = \mu_3$$

Thus, the angle of incidence ϕ in the first medium is the critical angle for the first and third media. That is to say, if the ray were to meet the interface of the first and third medium at this angle of incidence ϕ, the ray would have just grazed the interface. If the third medium be air, then,

$$\mu_1 \sin\phi = \mu_2 \sin\theta = 1$$

Then, ϕ and θ represent the critical angles for the first and second media with respect to air.

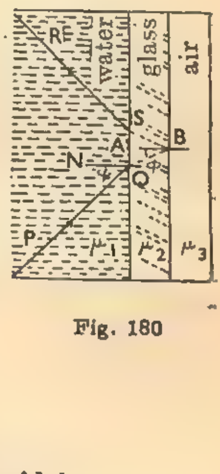


Fig. 180

Date—

EXPERIMENT 93

To Find the Reractive Index of a Liquid by Total Reflection Method

(Air Cell Method)

Theory—If ψ be the angle of incidence for a pencil of light travelling in a liquid just to graze after refraction the surface of air separating it, then the refractive index μ of the liquid is given by,

$$\mu = \frac{1}{\sin\psi}$$

Apparatus—A cubical glass vessel, air cell apparatus, sodium flame or two hair pins.

The air cell apparatus consists of a cubical glass vessel containing two plane parallel glass plate C having a film of air enclosed between two plates. The combination of the plates is held rigidly by a rod which can be rotated along a vertical axis. The rotation can be measured by the pointer correct to half a degree moving over a horizontal graduated disc D. (Fig. 181).

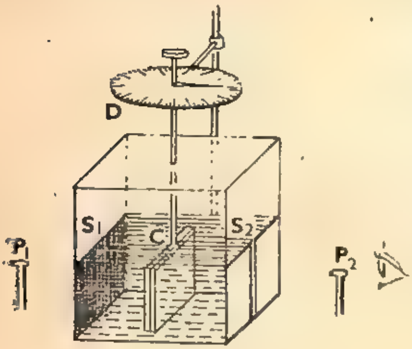


Fig. 181

Procedure—Fill the glass vessel with the liquid, under examination, say water and put the glass plates of the air cell apparatus within the liquid. At the middle of a pair of opposite faces of the glass vessel but just outside it, place two vertical linear apertures, each about half a centimetre wide. These two aperturess would cut off extra light which would otherwise pass through the apparatus. By rotating the top, place the pair of plates approximately at right angles to the line joining the centre of the apertures and look through the apertures. Place a pin vertically or a slit illuminated with sodium flame at a distant of 10 to 20 cm. such that it is clearly visible through the apertures.

Now fix your observation on the pin or flame and slowly rotate the top in a clock-wise direction. Just at the moment the image of the source disappears from view, read the position of the pointer (Fig. 182). On rotating the top more, the flame permanently disappears. Now rotate it in the opposite direction and just when the image comes into view, take the reading of the pointer again. Rotate the plate in an anti-clockwise direction. At some position of the plate, the image just disappears from the view. Take this reading of the pointer. Again rotate it in the opposite direction and take the reading when the image just appears. In this way take four or five pairs of readings and tabulate in the following way. If the two vertical apertures are not available, the experiment can be done by fixing two pins along a line at right angles to the edges of the glass vessel. The observation should always be made along the two pins.

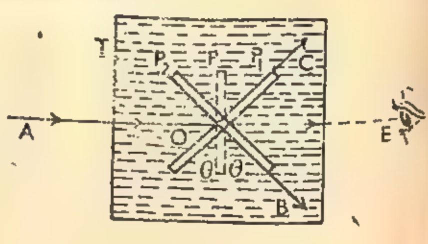


Fig. 182

Results—

No. of readings	Readings of the Pointer Right in Degrees			Readings of the Pointer Left in Degrees			Difference 2θ in Deg.	Mean θ Deg.
	Flame disappears	Flame appears	Mean	Flame disappears	Flame appears	Mean		
1.								
2.								
3.								

$$\therefore \quad \mu = \frac{1}{\sin \theta}$$

Discussions—Since the circle is graduated in half degrees, it is not possible to take the reading more accurately than half a degree. Consequently, the reciprocal of sine of an angle cannot be more accurate than two significant figures. Thus the accuracy with which μ can be determined is only upto one place of decimal. This apparatus can be made more accurate by attaching the rotatory system with the prism table of a spectrometer, the glass vessel being held suspended by suitable clamp. The spectrometer is previously adjusted for parallel rays, its slit serves as the source and telescope being kept permanently in line with the collimator. The angular measurements can then be done accurately upto half a minute or so and the value of μ comes to an accuracy of 3 places of decimals.

In doing this experiment a close attention is to be made against any liquid leaking into the air cell. The glass vessel should not be disturbed while taking readings.

Oral Questions

What is critical angle? What is the condition of total reflection? Explain how does the total reflection take place in your apparatus? The critical angle is met with the glass-air surface; how from this the critical angle is found in water air surface? Why it is called an air cell? What is the probable accuracy of your apparatus? Can you suggest any improvement of this, such that the refractive index may be measured more accurately? Can you cite a few every day instances of total reflection?

Refractometer

A refractometer is an instrument which may be employed to measure the refractive indices of solids or liquids. The following is a method of determining the refractive index of liquid based upon total internal reflection.

Let WXYZ be a cubical block of glass of refractive index μ_g standing upon a layer of liquid WIJX of refractive index μ_w of a

lesser value (Fig. 183). Let rays of light from an extended surface, *e.g.*, sky or a white wall, be incident on the face XY of the glass block and be transmitted into it in various directions. Consider the incidence of these rays at any point O of the glass liquid interface. It is evident from the figure that the higher is the point of incidence of light at the face YX, the lesser is the angle of incidence at the point O.

It is known that at the glass liquid interface when a ray is incident in glass at an angle less than the critical angle for the pair of media, major part of light is transmitted into water obeying the laws of refraction. So the ray BO meeting the normal PO at a small angle finds a refraction along OC, and similarly the ray EO although incident at O at the smaller angle than the critical angle is refracted along OF. Let a ray LO meet PO at an angle just greater than the critical angle, and since refraction is not possible in this case almost the total quantity of light will be reflected in the direction OM. Any ray of light below L will meet O at an angle greater than critical angle and hence it will be reflected making an equal angle with the normal PO. Hence in so far as the incidence of light at O is concerned, the part ZM will appear darker and MW brighter when observation is made on the face ZI. In fact the face ZW will appear partly shaded and partly illuminated and there will be a sharp line of demarcation between the two parts passing through the point M.

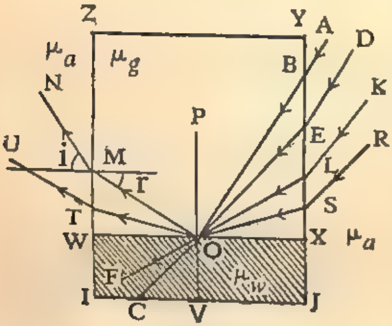


Fig. 183

Since POL is the critical angle between glass and liquid,

$$\sin \text{ POL} = \sin \text{ POM} = \frac{\mu_w}{\mu_g}$$

And $\dfrac{\sin i}{\sin r} = \dfrac{\mu_g}{\mu_a} = \mu_g$, since μ_a for air $= 1$

Again POM $= 90 - r$, hence $\sin \text{POM} = \sin (90 - r) = \cos r$

$$\therefore \quad \frac{\mu_w}{\mu_g} = \cos r = \sqrt{1 - \sin^2 r} = \sqrt{1 - \frac{\sin^2 i}{\mu_g^2}}$$

Hence $\mu_w = \sqrt{\mu_g^2 - \sin^2 i}$

Thus knowing i and μ_g, μ_w can be determined. This principle is applied in a modified form of apparatus known as Pulfrich Refractometer.

Date— EXPERIMENT 93

To Determine the Refractive Index of a Liquid using Total internal Reflection Method (Following Pulfrich Refractometer)

Theory—If i is the maximum angle of emergence at which light can just pass out from the edge of a glass cube by undergoing total reflection at the glass water surface at the base of the cube then,

$$\mu_w = \sqrt{\mu_g{}^2 - \sin^2 i}$$

where μ_g and μ_w are the refractive indices of glass and water respectively.

Apparatus—A simple form of Pulfrich refractometer.

The apparatus, consists of a rectangular horizontal platform L on which a cubical block of glass B can slide (Fig. 184). There are two vertical rods RR rigidly fixed at the end of the platform, along which a metal plate S having an adjustable horizontal slit can slide. The plate can be clamped anywhere on the rods. The upper surface of the platform L is usually painted black to prevent diffused reflection of light to reach the eye. A piece of black paper is pasted at one side of the block so as to cover some part of it from the bottom.

Procedure—Put a few drops of the liquid, say water, on the platform L. Paste a piece of black paper with a horizontal edge on the lower portion on one side of a glass cube and place the glass cube upon water with the black paper facing the slit S. Mount the slit S horizontally to the stand R at the top position and look through the slit towards the upper edge of the black paper. If necessary place the apparatus facing a window so that sufficient sky light may fall on the glass cube A hazy background would ordinarily be observed. Now lower the slit gradually till the hazy background just transforms into a bluish tinge. This is the stage at which the internally reflected rays can just pass out. Measure the height of the slit from the plane of the platform with a metre scale. Let it be h_1. Next slightly lower the slit when the background appears fully illuminated due to total internal reflection. Again raise the slit slowly until the bluish tinge again appears Measure the height h_2 of the slit above the platform with the metre scale. The mean of these two gives the actual height h of the slit. Repeat such observations three or four times and get the mean height of the slit.

Measure the distance from the base of the rod R to the nearest edge of the block three times and get the mean. Let it be l Measure with a diagonal scale or slide callipers the height of the

edge of the black paper from the base of the block three times and get the mean; let it be d.

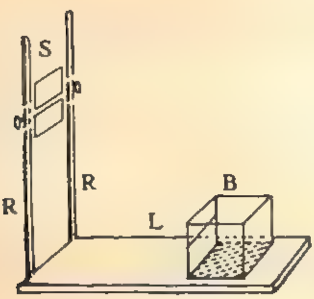


Fig. 184

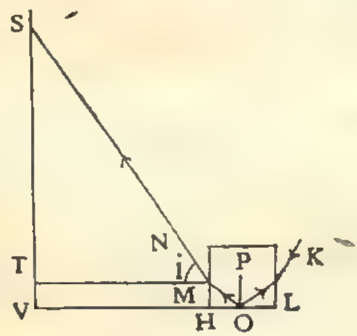


Fig. 185

Then according to Fig. 185, $\sin i = \frac{TS}{SM} = \frac{SV - VT}{\sqrt{ST^2 + TM^2}}$

$= \frac{h-d}{\sqrt{(h-d)^2 + l^2}}$. So measuring h, d and l find sin i.

Finally from the formula $\mu_w = \sqrt{\mu_g^2 - \sin^2 i}$, μ_g being supplied calculate μ_w.

Results—

Height of the slit from the base while moving downwards =
Height of the slit from the base while moving upwards =
Distance of the edge of the block from the rod =
Height of the edge of the black paper =
Refractive index of the material of the block =
Hence μ_w =

Discussions—The accuracy of the method lies in setting the slit just at the position when a uniform brightness or darkness suddenly changes to greenish violet colour which is the point of total reflection. For greater accuracy the heights SV and TV may be measured with a cathetometer, the slit being very narrow.

Oral Questions

Define relative and absolute refractive indices. What is meant by critical angle? Give the conditions of total internal reflection in a medium. Can you cite a few common examples of total reflection? What is a refractometer and what are its functions? What are the advantages of a total refraction refractometer? Why at a certain position of slit a greenish blue colour is seen?

Spherical Mirrors

A reflecting surface which forms a part of a sphere is called a spherical mirror. When reflection occurs from the hollow side, it

is called a concave mirror; whereas if the reflection takes place from the raised side, it is called a convex mirror. The *centre of curvature* of a mirror is the centre of the sphere of which the mirror is a part and the radius of such a sphere is called the *radius of curvature* of the mirror. Fig 186 represents the section of a

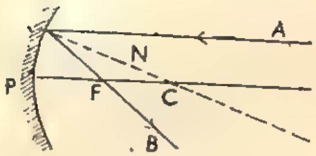


Fig. 186

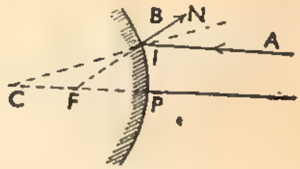


Fig. 187

concave mirror, the point C being its centre of curvature and PC its radius of curvature. The corresponding figure for the section of a convex mirror is shown in Fig 187. The pole of the mirror is the central point of the reflecting surface. The point P for both the figures, representing the central point of the reflecting surface, is the pole The *principal axis* is the straight line passing through the pole and the centre of curvature of the mirror. In both cases the straight line passing through the points P and C represents the principal axis of the mirror. The principal section of the mirror is a section by a plane passing through the principal axis of the mirror. All the sectional diagrams of mirrors and lenses drawn in this book give the principal sections. The aperture of mirror is measured by the angle subtended by its principal section at the centre of curvature. The apertures of the mirrors and lenses herein dealt with are supposed to be small.

If a parallel beam of light parallel to the principal axis be incident on a concave mirror, the beam after reflection converges to a point on the axis called the **principal focus**. The distance of this

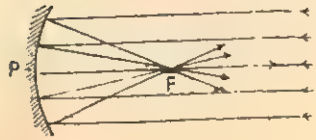


Fig. 188

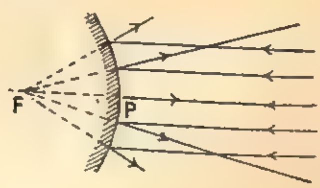


Fig. 189

point from the pole is called the *focal length* A beam of light parallel to the principal axis in the principal section of a concave mirror is incident as shown in Fig. 188, F being the principal focus and PF the focal length. The focal length of a spherical mirror of small aperture is half the radius of curvature. If a plane is drawn through the focus at right angles to the principal axis, it is called a focal plane. Any group of parallel rays incident on the

mirror converges to a corresponding point on the focal plane. In case of a convex mirror a group of parallel rays parallel to the principal axis after reflection diverges in such a way as to come out from a point on the axis which is called its principal focus. Fig. 189 shows how a group of parallel rays are reflected from a convex mirror. F is its principal focus. The focal length and its relation to the radius of curvature are exactly alike (for details, vide Basu & Chatterjee's Intermediate Physics, Light, Chap. III.)

The image of a point source of light due to reflection at a spherical mirror is drawn geometrically with the help of *any two* of the three typical rays proceeding from it, as given below,—

(i) A ray incident parallel to the axis—the reflected ray produced, if necessary, passes through the principal focus.

(ii) A ray incident in a direction passing through the centre of curvature—the reflected ray goes back along the same path.

(iii) A ray incident in a direction passing through the principal focus—the reflected ray becomes parallel to the principal axis.

Date—

EXPERIMENT 94

(Pin Method)

To Determine the Focal Length of a Concave Mirror by Coincidence method

Theory—The focal length of concave mirror is half its radius of curvature. If an object is placed at the centre of curvature of a concave mirror, its image is formed of the same size and at the same place.

Apparatus—An optical bench, a concave mirror and a long pin. An optical bench consists of a long horizontal bed mounted upon levelling screws. There is a metre scale fixed along side the bed (Fig 190). Two or three vertical stands, capable of sliding over the bench, can be fixed at any position upon it by screws. Each stand is hollow and is provided with a screw at the top so that a thin rod can be clamped vertically with it. A mark at the base of each stand facilitates the reading of its position on the scale.

Procedure—Mount a concave mirror O to a vertical stand in a manner as shown in Fig. 190 and slide the stand near to one end of the optical bench. Fix a long pointer P vertically to the other stand. Bring the stand, carrying the pointer close to the mirror so that the tip of the pointer almost touches the reflecting surface of the mirror. Now adjust the height of the pointer so that its head is very nearly at the pole of the mirror. This adjustment ensures that the head of the pointer would always lie on the principal axis

of the mirror, whenever may be its position on the optical bench, provided the stands are vertical. When very near the pole, an erect image of the pointer is observed. Now, slowly move the stand carrying the object away from the mirror and keep an watch over the image. You would find that the image appears to be bigger and bigger remaining erect. If the image gradually moves to *one side*, tilt the mirror slightly along the vertical axis to bring the image on the axis of the optical bench. By moving away the pointer in this way, you would get a certain position of the stand for which

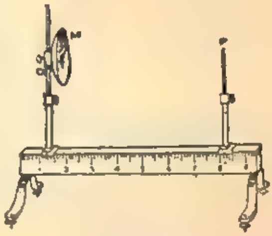


Fig. 190

the image becomes very big but indistinct. The position of the pointer is then very near the focus of the concave mirror. Beyond this position the nature of the image is changed, for now it becomes inverted. Move the stand further away until the inverted image appears to be of the same size as the object. Now move your head slowly left and right, and observe the relative shift of position between the pointer head and its image. If there is parallax, as shown by three positions in Fig. 191*a* *slightly* shift the position of the pin and try to remove the parallax. At the right position of the pin the image would move always touching it for a slight swinging of the head as shown by the three positions in Fig 191*b* Thus parallax has been removed. Take the readings of both the stands. Slightly alter the position of the pin and repeat the same procedure to remove the parallax and take another reading for the pin position. In this way take three or four readings for the position of the pin. Finally to get the true distance between the pole of the mirror and the pin make the index correction in the following way.

Take a straight rod and measure its length correct to a millimeter. Let its length be x cm. Place the rod horizontally parallel to the bed with one of its ends touching the pole of the mirror. Now slide the stand carrying the pin so that other end of the rod touches the pin. Take the readings of both the stands. Let the difference

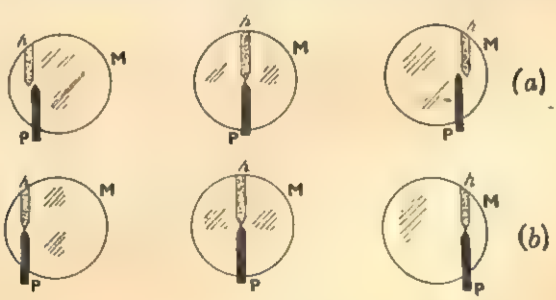


Fig. 191

of readings be y cm. The true distance between the pole and the pin at this position is x, while the apparent distance as recorded by the stands is y. The quantity $x-y$ is called the index correction. To get the radius of curvature add it to or subtract it from the apparent distance according as it is positive or negative.

Results—

No. of readings	Position of mirror	Position of pin	Apparent distance	Mean distance	Index correction	Radius of curvature	Focal length
	cm.	cm.	cm.	cm.	cm.	cm	cm
1.	10 0	42·3	32·3				
2.	...	...	...	32·2	−2·1	30·1	15·05
3.	...	...	...				

Length of the index rod = (i) 12 cm. (ii) 12·1 cm. (iii) 12·05 cm. Hence mean length of the rod = 12·1 cm.

Apparent distance between the pin and the mirror when the index rod touches them :—

$$\left.\begin{array}{ll}\text{(i)} & 24{\cdot}2 - 10{\cdot}0 = 14{\cdot}2 \text{ cm.} \\ \text{(ii)} & 24{\cdot}1 - 10{\cdot}0 = 14{\cdot}1 \;\;\text{,,} \\ \text{(iii)} & 24{\cdot}2 - 10{\cdot}0 = 14{\cdot}2 \;\;\text{,,}\end{array}\right\} = 14{\cdot}2 \text{ cm. mean}$$

Hence index correction = 12·1 − 14·2 = −2·1 cm.

Discussions—The position of any stand can be read correct to a millimetre on the optical bench. Hence the mean focal length expressed in centimetres should be taken correct to one decimal place only. If the aperture of the mirror be moderately large, the principal focus is not a point on the axis but extends to a very short range. It is not possible in such a case to avoid parallax completely between the pin and its image.

Measurement of Radius of Curvature with a Spherometer

The radius of curvature of a concave mirror, as discussed in Experiment 7, can be measured with a spherometer to compare the result with that found in the previous experiment. To do this, the mirror is placed upon a tripod stand with its reflecting face upwards and readings are taken with a spherometer whence the radius of curvature is determined.

Conjugate Foci

An object placed at any distance in front of a spherical mirror must have an image at a corresponding distance from the mirror. The positions of the object and its image are interchangeable. Two points are said to be at conjugate foci when a point source of light being placed at any one, image is formed at the other. If u denotes the distance of the object from the pole of the mirror, v the distance of the image and r the radius of curvature of the mirror, then the relation between these quantities is given by the following equation,—

$$\frac{1}{v}+\frac{1}{u}=\frac{2}{r}=\frac{1}{f}$$

This equation is to be applied with the proper algebraic signs of the quantities involved according to *the convention of signs*, which

states that distances are always to be measured from the pole and that distances measured against the direction of the incident light are taken as positive while those measured in opposite direction are negative. (For details, vide Basu and Chatterjee's Intermediate Physics, Light).

Date—

EXPERIMENT 95

To Determine the Focal length of a Concave Mirror by Conjugate Foci or U-V Method

(Pin-Method)

Theory—If the distance of an object from the mirror be u and the distance of the image be v, then the focal length f of the mirror is given by the equation $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

Apparatus—An optical bench, a concave mirror, two hair pins.

Procedure—Mount the concave mirror on a stand and place it nearly at one end of the bench as shown in figure 192. Fix up a pin P on a vertical stand, preferably with its point upwards, and adjust the height of the pin point so as to touch an imaginary horizontal line drawn from the pole of the mirror. you would then observe an image of the pin. Move the pin away from the mirror and follow the image. If the image is found to stray away from the line of sight joining the pin point and the pole, turn the mirror along the vertical axis to bring the image on this line. Remove the pin to such a distance that its image appears to be inverted. Now fix up another pin Q in a similar way on another stand at an equal height and adjust its distance by trial to such a position that the image of P just touches Q. Avoid parallax between Q and the image of P each time you make the adjustment.

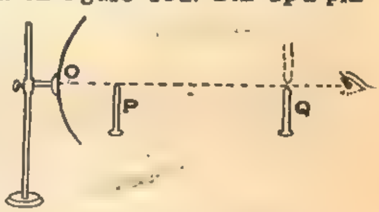


Fig. 192

Read the positions of the mirror, pin P and pin Q from the scale attached to the optical bench. Find correct lengths u and v by index correction according the directions supplied in Expt. 94. Take a number of readings (four to six) for u and v altering the position of P each time. Calculate the focal length in each case from each pair of readings of u and v and thence find the mean value of the focal length.

Results—

Mean length of index rod = 12·1 cm. (suppose).

Mean apparent distance between the pin P and the mirror when index rod touches them = 14.2 cm. Hence index correction for u is 12.1 − 14.2 = −2.1 cm. Similarly, make index correction for v which is, say, − 2 cm.

No. of readings	Position of mirror	Position of object	Apparent object Distance	Index correction for u	Corrected u	Position of Image	Apparent Image distance	Index correction for v	Corrected v
	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm	cm.
1.	4.0	24.1	20.1	−2.1	18.0	46.9	42.9	−2.0	40.9
2.	...	...	...	...	20.1	...	...	...	32.4
3.	...	...	...	...	23.3	...	...	...	...
4.	...	...	...	...	...	...	...	...	24.9
5.	...	...	...	...	...	...	...	...	27.4

No. of readings	Corrected u	Corrected v	uv	$u+v$	$f=\frac{uv}{u+v}$	mean f
	cm.	cm.	cm².	cm.	cm.	cm.
1.	18.0	40.9	736.2	58.9	12.5	
2.	20.1	32.4	...	...	12.4	
3.	...	...	...	...	...	12.5
4.	23.3	29.2	...	...	12.6	
5.	...	27.4	...	...	12.5	

Discussions—The same as that of the preceding experiment.

Graphical Method of Finding Focal Length

There are various ways of finding focal length by graphical solution from a series of data for conjugate foci. Such methods are applicable to the cases of real image formations in spherical mirrors and lenses, One method is described here and other two methods would be dealt with in Expt. No. 90.

Proceed on with the Expt. 95 as usual and make the tabulation of the data collected. Second tabulation for calculating mean focal length *is not necessary*. Do not take very large values of the object or the image distances usually exceeding 60 or 70 cm. Since graphical plotting of such large values of u and v requires a large graph paper which is not ordinarily available, whereas in an ordinary graph paper, inconveniently small units have to be chosen to get such values of object and image distances.

Take a graph paper containing 60 on 70 small divisions on each side and choose the origin O of co-ordinates near at the left bottom corner of the paper. Let the abscissa OX represent the object distance. Mark off 0, 10, 20, etc., starting from the origin to represent

distances in centimetres. Similarly, mark off distances along OY showing image distance. It is convenient to have the length of the units chosen equal along both the axes, for example, 1 small unit having a value of 1 cm. or if the size of the paper permits, 2 small units for a length of 1 cm. But it is essential that the values of the of-ordinates at the origin should be put equal, preferably $0-0$, in this experiment.

Now take any pair of values for corrected u and v, say 18·0 and 40·9 cm. Along abscissa count 18 cm. and put a *fine* pencil dot and along ordinate count 40·9 or rather 41 cm. and put another dot. Then join these two dots by a straight line with a metre scale. This is shown as CH in Fig. 193. Then take the next pair of u and v, and in a similar way get another two dots on the co-ordinate axes. Also join them by a straight line. In this way draw straight lines corresponding to all pairs of collected data. Theoretically all the straight lines so drawn would *pass through a point* on the graph paper and the co-ordinates of this point would be (f, f). But in practice, if your observations are sufficiently accurate, these straight lines would pass through a *very small area* on the graph paper, probably covering an area of a small square. Then count the distances of the *centre of this square* from the co-ordinate axis in terms of units chosen. Take the mean value of the two distances, which give the required focal length. In case you have taken one small division as 1 cm., you can graphically find the value of f correct to half a centimetre and not beyond it by eye-estimation. The value of f according to Fig. 193, is thus 12·5 cm.

It may be mentioned in this connection that the method of calculating focal length of each set of readings and thence to find the mean focal length gives a more accurate value of the observed focal length than the graphical method which is done in the ordinary way. Since the accuracy of measurement of u or v is about 0·1 cm., the mean focal length comes out accurate to 0·1 cm., but the graphical method, in which a small division represents 1 cm, does not with eye-estimation give an accuracy of not beyond 0·5 cm. or 0·25 cm., on the shorter side. But the graphical method is convenient inasmuch as it saves a lot of calculations.

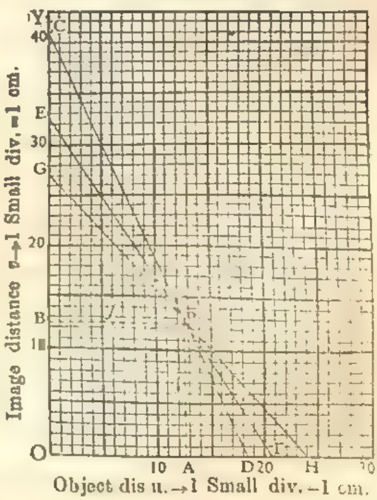


Fig. 193

Theory of the Graphical Method—The equation of any straight line in rectangular co-ordinate OY and OX is given by $y=mx+c$, where y and x represent the co-ordinates of any point on that line. The co-efficient m indicates the tangent of the angle between the straight line and OX, and c represents the value of the intercept of OY between the origin and the junction of the straight line with OY. The values of m and c may be positive or negative according as the tangent of the angle and the intercept are positive or negative. The equation of the straight line EF (Fig. 193) is given by,

$$y=x\tan\angle EFX+OE=-\frac{v_1}{u_1}x+v_1 \quad \ldots \quad (1)$$

where $OE=v_1$ and $OF=u_1$ (say).

For the same reason, the equation of the straight line CD

$$y=x\tan\angle CDX+OC=-\frac{v_2}{u_2}x+v_2 \quad \ldots \quad (2)$$

where $OC=v_2$ and $OD=u_2$ (say).

At the junction P of these straight lines, since y and x are equal,

$$-\frac{v_1}{u_1}x+v_1=-\frac{v_2}{u_2}x+v_2,\ \text{whence}\ x\left(\frac{v_2}{u_2}-\frac{v_1}{u_1}\right)=v_2-v_1 \quad \ldots \quad (3)$$

Again for real images, $\frac{1}{v_1}+\frac{1}{u_1}=\frac{1}{f}$ also $\frac{1}{v_2}+\frac{1}{u_2}=\frac{1}{f}$

Multiplying the first by v_1 and the second by v_2, we get

$$1+\frac{v_1}{u_1}=\frac{v_1}{f}\ \text{and}\ 1+\frac{v_2}{u_2}=\frac{v_2}{f}\ \text{whence}\ \frac{v_2}{u_2}-\frac{v_1}{u_1}=\frac{v_2-v_1}{f}$$

Substituting in equation (3), we get

$$x\left(\frac{v_2-v_1}{f}\right)=v_2-v_1 \quad \therefore \quad x=f$$

Substituting the value of $x=f$ in equation (1) and writing $\frac{v_1}{u_1}=\frac{v_1}{f}-1$ it can be proved that $y=f$ for the same point P. Thus the junction of all straight lines drawn in this way would bear the same co-ordinates $(f, f.)$.

Oral Questions

Define the focal lenth of a spherical mirror. How does a convex mirror differ from a concave one? Define the centre of curvature of a spherical mirror? What is a method of parallax? What is index correction? What is the quickest and ready method of determining the focal length of a concave mirror? Why in large spherical mirrors parallax cannot be fully corrected for all angles of vision even at the correct position?

Localisation of a Virtual image

A real image is formed by the actual intersection of reflected or refracted rays and hence it can be received on a screen. But a

virtual image is formed at a position where a divergent group of reflected or refracted rays produced backwards meets. It can be seen when eye is *suitably placed* but the image cannot be received on a screen. To detect the position of virtual image a plane mirror is sometimes used in front of the object ; the position of virtual image formed by this mirror is always known. By suitably adjusting the position of the plane mirror, the virtual image of this mirror is made to coincide with the virtual image under investigation, the method of coincidence being tested by the method of parallax. Another way of detecting the position of a virtual image is to fix up a thin and straight rod near about the position of the virtual image so that both are simultaneously visible. Then the rod is adjusted to such a position that there is no parallax between the two. Finally, the object and the image distances are ascertained from the pole of the mirror whence the focal length is determined.

Date— EXPERIMENT 96

To Measure the Focal Length of a Convex Mirror by Plane Mirror method and to check it by Spherometer

Theory—If u is the object distance, v the image distance and f the focal length of a spherical mirror, then

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

But in a convex mirror the focal length and the image distance are negative and hence $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$

Apparatus—Optical bench, convex mirror, one long pin and a plane mirror.

Procedure—Fix the convex mirror O with a vertical stand of the optical bench and place it near the end of the bench. Fix a plane mirror M vertically to another stand such that the upper edge of the plane mirror touches the pole of the convex mirror. Place both the mirrors with their reflecting surfaces facing the other end of the bench (Fig. 194). Clamp a long pin P vertically on

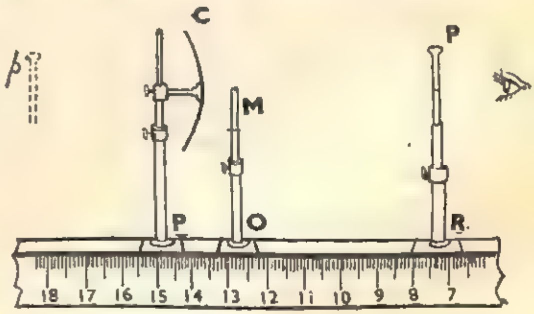


Fig. 194

another stand at the other end of the table. On now looking in the direction of the mirrors you would be able to see two halves of the

images of the pin. One image is due to the convex mirror, which is virtual, erect, smaller in size and is formed somewhere behind the mirror. The other image is due to the plane mirror, which is also virtual, erect and of the same size as the object. A slight turning of the mirrors may be necessary to bring the images on a line. Now if you move your head slowly to the left and right, you would find a relative change of positions of these two images, showing that these two images are not generally formed at the same place. Now slowly move the mirror M and at the same time try to avoid parallax between the two images. When for a certain position of the mirror M the two images appear to move together, the image due to the plane mirror is at the same position as that due to convex mirror.

Then read the position of the pin, plane mirror and the convex mirror on the optical bench. Change the position of the pin by about 2 to 3 cm. and again adjust the position of the plane mirror to avoid the parallax between the images and take a fresh set of readings. In this way take four or five set of readings.

Make the index corrections of the object distance between the pin and the convex mirror and that between the pin and the plane mirror which is connected with the image distances. Let the corrected distance from convex mirror be u and corrected ditance from plane mirror be d. Then the corresponding image distance v is $2d-u$. From a pair of values of object and image distances, calculate the focal length. The mean value of the focal length gives the result required.

Results—

Index correction for $u=2{\cdot}4$ cm.

Index correction for $d=0{\cdot}3$ cm.

No. of readings	Position of the pin	Position of convex mirror	Difference	Corrected object distance u	Position of Plane mirror	Difference	Corrected d	$v=2d-u$	$f=\frac{uv}{u-v}$
	cm	cm.	cm.	cm.	cm.	cm.	cm	cm.	cm.
1.	7·2	34·8	27·6	25·2	24·4	17·2	17·5	9·8	16.1
2.	...	...	...	...	...	...	...	...	16.0
3.	...	30·2	...	20·6	...	...	...	9·0	16.1
4.	...	...	...	...	...	...	...	...	...
5.	...	...	...	...	...	...	...	...	16·1

∴ mean $f=16{\cdot}1$ cm. so radius of curvature $=32{\cdot}2$ cm.

Least count of the spherometer $=$ ·005 mm. $=$ ·0005 cm.

Mean difference of disc readings on the convex and plane surface $= (\cdot5 + 51 \times \cdot005)$ mm. $= \cdot0755$ cm. $= h$.

Mean distance between spherometer legs $= 3\cdot8$ cm. $= c$.

$$\therefore \quad R = \frac{c^2}{6h} + \frac{h}{2} = \frac{3\cdot8^2}{6 \times \cdot0755} = 31\cdot8 \text{ cm.}$$

Hence percentage of difference in results $= 1\%$ nearly.

Discussions—The coincidence of the two virtual images should be done very accurately which depends upon the accuracy with which the parallax between two observed images may be avoided. The adjustment of the two mirrors should be done in such a way and observation should be made from such a position that the image of the upper half of the pin is seen in the convex mirror and that of lower half in the plane mirror. It is then much advantageous to examine the coincidence of the images and to test for parallax. For any fixed position of the pin, the readings for the position of the plane mirror may be taken two or three and its mean position may be calculated to get more accurate results. It would be of advantage if a pin coloured white is taken as the object.

Oral Questions

What is the nature of the image in a convex mirror? Why it is erect? Distinguish between a real and a virtual image. Why a screen is not used to receive the image? Define the principal focus of a convex mirror. Why the aperture of the mirror should be small? How can you arrange to get a real image from a convex mirror? Give a practical illustration of the use of a convex mirror.

Lenses

A lens is a portion of transparent medium bounded by two spherical surfaces. The line joining the centres of curvature of the spherical surfaces is called the principal axis of the lens. The lenses may be divided into two classes: those thicker at the middle part and thinner at the edge: these are called convex lenses. The other class, which are thinner at the middle and thicker at the edge, are called concave lenses. A convex lens may be bounded by two spherical surfaces which have their centres on both sides of the lens in which case it is called a double convev (Fig. 195A). If the centres lie on the same side, it is called a convex meniscus (Fig. 195B). If

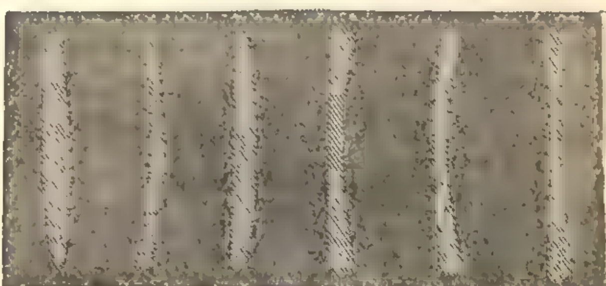

A B C E F G

Fig. 195—Types of Lenses

one side of the lens is plane and the other side curved it is called a *plano convex lens* (Fig. 195C). Similarly, there are three types of concave lenses called plano-concave (Fig. 195E), concave meniscus (Fig. 195F) double concave (Fig. 195G) If the two radii of curvatures of a convex or a concave lens be equal to each other it is called an *equi-convex* or *equi-concave* lens.

Date— **EXPERIMENT 97**

To Determine the focal length of a Convex lens by Conjugate foci or $u-v$ Method

Theory—If an object, placed at a distance u from a convex lens produces a *real* image on a screen at a distance v from the lens, then its focal length f is given by the expression,—

$$\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$$

Apparatus—An optical bench, a candle flame, a lens, a holder and a paper screen, or two pins instead of the candle flame and the screen. (Description of an optical bench is necessary.)

Procedure—Mount a pin or a candle stick on a stand at one end of the optical bench (Fig. 196). Place the lens L in the holder on the middle stand. Mount a paper screen (in case of a candle flame) or a pin (in case of a pin object) upon a third stand. Place the three stands close together and adjust the heights of all the three so as to make axis of the system horizontal. In case of flame as the object, make the centres of the flame, the lens and the screen horizontal. In case of two pins, make the heads of the pin and the centre of the lens horizontal. Now move the stand carrying the lens to distance so as to get a real image of the flame or the pin at O, which serves as the object. Move the screen S away from the lens, until for a certain position a sharp image on its surface is obtained. When pin stands for the object, look for its inverted image from the other side of the lens and by the second pin remove the parallax between it and the image. Take the readings for the positions of object and lens and the image on the optical bench. For a given

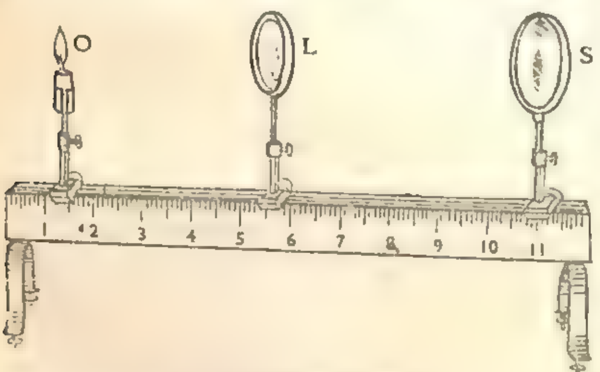


Fig. 196—Optical Bench

position of the object and the lens, two readings for the positions of the screen or pin should be taken,—when it is approaching and when it is receding. The mean of these two readings gives the real position of the image. Alter the position of the lens three or four times and in each case and find the corresponding position of the image. Thus a number of object and image distances are obtained. Make index correction for the object and image distance and then from the formula find the focal length.

Results—For tabulation of data vide Expt. 95 :—Determination of focal length of a concave mirror by $u-v$ method.

Discussions—The same as Expt. 95. Instead of a candle flame serving as the source of light, a pin or a crossed mark on a piece of paper might serve as the object. The image position is then located by the method of parallax on a suitable screen.

Graphical Methods of Measuring Focal Length

One graphical method has been described in connection with Expt. 95. Other graphical processes, in which the focal length can be found, are discussed in this article. Proceed on with Expt. 97 as usual and make a tabulated chart of collected data. As an illustration, suppose that the data that you have obtained experimentally are as follows :—

No. of readings	Position of the Object (a)	Position of the Lens (b)	Apparent Object Distance $b-a$	Index Correction for u	Corrected u	Position of the Image (c)	Apparent Image Distance $c-b$	Index Correction for v	Corrected v
	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
1	5·0	65·6	60·6	−0·4	60.2	94·2	28·6	+0·3	38·9
2	,,	57.8	52·8	,,	52.4	88·6	30·8	,,	31·1
3	,,	46·2	41·2	,,	40.8	83·3	37·1	,,	37·4
4	,,	37·8	32·8	,,	33·4	86.6	48·8	,,	49·1
5	,,	91.0	29·0	,,	24.5	95·0	61·0	,,	61·3

On a graph paper take *equal length for the units* along the two rectangular axes representing object distance u and image distance v, generally 1 or 2 small divisions for 1 cm The chosen origin of the co-ordinate axes must have *equal values for* u and v.—either O—O or some convenient equal values. In Fig. 133, the origin of the co-ordinates is for $u=v=20$ cm. Then plot the points for the corresponding pairs of values of u and v, and draw a free-hand curve through these points. The nature of the curve is an arm of a hyperbola, as shown by ABCDE.*

* $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}=$ constant k, whence $v+u-kvu=o$. This is the equation to hyperbola in which the coefficients of second degree powers in u and v are zero.

Then from the origin draw a straight line OP at an angle of 45° to any axis intercepting the curve at the point P. Then the point P, being equidistant from both the axes, would have equal values of co-ordinates. Find any co-ordinate of this point in terms of units chosen and this would be $2f$. So half this value is the required focal length.

The graphical method of finding focal length is less troublesome than that described in Expt. 95, because the co-ordinate of a single point is to be determined in it, whereas in the other the co-ordinate of a mean point of a small area is to be found. The accuracy of both these methods is equal, being 0·5 or 0·25 cm. depending on the size of the units chosen on the graph paper.

Theory of the Method—Since any point on the curve ABCDE corresponds to a pair of values of u and v, then the curve in general represents the $u-v$ relation for real images. We know that in case of real images due to mirrors or lenses, the equation for u and v is given by,

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f} \qquad \ldots \quad \text{(i)}$$

Hence this equation represents the general equation of the curve in co-ordinate axes v and u. This curve is an arm of a hyperbola. Again for the straight line OP, equally inclined to the axes, its equation is given by

$$u=v \qquad \ldots \quad \text{(ii)}$$

Hence at the point of intersection P, both these conditions would be satisfied. Hence writing $u=v$ in equation (i), we get at P,

$$\frac{2}{v}=\frac{1}{f} \text{ or } v=2f \text{ and similarly } u=2f.$$

Reciprocal Method—In this method the tabulation should be slightly modified in the following way :—

No. of Readings	Corrected Object distance u	Reciprocal of Object distance $\frac{1}{u}$	Corrected Image distance v	Reciprocal of Image distance $\frac{1}{v}$
	cm.	cm^{-1}	cm.	cm^{-1}
1.	60·2	·0166	28·9	·0346
2.	52·4	·0191	31·1	·0322
3.	40·8	·0245	37·4	·0268
4.	32·4	·0308	49·1	·0204
5.	28·6	·0345	61·3	·0163

The reciprocal of any number is conveniently obtained from the Table of reciprocals in any book of Log Tables. Since the readings for u and v are correct to 1 place of decimal after two integers (3 significant figures), that is upto fourth place of decimals because zero everywhere occurs at the first place of decimal.

On a graph paper choose two rectangular axes to represent $1/u$ and $1/v$, and mark off units *of the same size and starting from zero values.* For convenience take each small division to be ·001 cm.$^{-1}$, or if the size of the paper permits, you may take 2 small divisions to be ·001 cm.$^{-1}$. Then plot the points corresponding to conjugate value of $1/u$ and $1/v$. If the readings are accurate these points will be found to lie *almost in a straight line.* Now with a fine pencil and a metre scale, pass a straight line evenly through these plotted points such that the line *makes equal intercepts with the two co-ordinate axes.*

The nature of the straight line and the probable positions of the points are shown in Fig. 193. Now find the value of any intercept OR or OQ which has been made equal by the process of drawing. Then find the reciprocal of this intercept, which gives the focal length in cm.

This graphical method is most accurate for the two following reasons. Firstly, there is no uncertainty about the practical location of the point whose co-ordinate value would give the focal length, as is described in Expt. 95. Secondly, there is no uncertainty about the exact nature of the graph obtained since it is a straight line, but much of uncertainty lies in the free- hand curve of the second graphical method described earlier in this article. Moreover there is this advantage here that the position of the straight line to be drawn can be judged accurately from the relative positions of the plotted points and from the condition that the straight line cuts equal intercepts at the two axes.

To read the intercepts an eye estimation to *a tenth of a small division can be made* in this case with a magnifying glass. The value of OP or OQ in this case is ·0513 cm.$^{-1}$. Hence,

$$f=\frac{1}{\cdot 0513}=19\cdot 5 \text{ cm. being accurate upto } 0\cdot 1 \text{ cm.}$$

Theory of the Method—If $1/u$ be p and $1/v=q$, then the conjugate foci relation for a real image can be expressed in the form,

$$p+q=\frac{1}{f}=\text{const. for a given lens or mirror.}$$

Thus the graphical relation between p and q is a straight line. At the point where this straight line cuts the q-axis, the value of p is zero. If q_1 is the value of q at this point, then

$$q_1=\frac{1}{f} \quad \text{whence } f=\frac{1}{q_1}.$$

Again where this straight line cuts the axis of p-axis, $q=0$. If p_1 is the value of p at this point, then also

$$p_1=\frac{1}{f} \quad \text{whence } f=\frac{1}{p_1}.$$

Thus $p_1=q_1$, or the straight line makes equal intercepts with the co-ordinate axes representing reciprocals of object and real images,

distance and the reciprocal of any intercept represents the required focal length.

Date—

EXPERIMENT 98

To Measure the focal length of a Convex Lens by Plane Mirror Method

Theory—If an object be placed in front of a convex lens with a plane mirror behind it such that the image is formed at the same position as the object, then the distance of the object from the lens is the focal length of the lens.

Apparatus—A convex lens, a plane mirror, a long pin and an adjustable holder.

Procedure—Place the plane mirror M horizontally on the table and wipe off any dust or grease that may stick on it. Clean the convex lens and put it on the mirror (Fig. 197). Fix a pin P in a horizontal position above the lens on an adjustable vertical stand and look vertically towards the lens with your eyes about a foot higher than P. You would then observe an image of the pin due to the lens-mirror combination. This image is due to the combined refraction through the lens and reflection by the plane mirror. Looking along this line, adjust the position of the pin so that the pin and its image appear to touch each other. Now move your head side to side and try to remove the parallax between these two by adjusting the position of the pin up or down. When such a position of the pin is obtained, the vertical distance OP from the pin to the upper surface of the lens gives the required focal length.* Measure the distance OP with a metre scale In this case also take a number of readings for the position of the pin by repeatedly adjusting it at the proper position. Measure the thickness of lens with a slide callipers correct to a millimetre only. Add one-third the thickness of the lens to the mean value of OP to get the correct focal length.

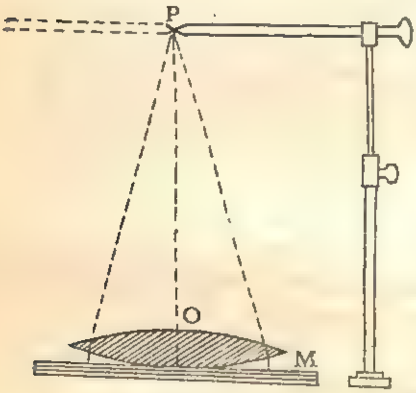


Fig. 197

*In case of a thin lens, it is immaterial whether the focal distance is measured from the optical centre of the lens or from its upper surface. In case of a thick lens, the focal length should be measured from a nodal point of the lens which is situated at a depth of one-third the thickness of the lens below the upper surface.

Results—

(Details of measurement of the thickness of lens to be given.)

No. of Readings	Position of P	Position of O	Difference of P & O	Mean	½ thickness of lens	Focal length
	cm.	cm.	cm.	cm.	cm.	cm.
1.	19·7	0	19·7			
2.	...	...	...			
3.	19·6	0	19·6	19·6	0·3	19·9
4.	...	...	...			
5.	19·6	0	19·6			

Discussions—The equation of a thin lens is derived on the assumption that its thickness is negligibly small as compared to its focal length. Therefore, for thin lenses the distance of the focus from the surface of the lens gives its focal length. If the lens supplied is appreciably thick, the focal length is to be measured from a point inside the lens which is called its corresponding *nodal point*. This point is generally found to be at a distance of one-third the thickness of the lens from its upper surface. For a thick lens it is difficult to avoid parallax for all positions of the eye. The approximately best position of coincidence is then to be sought for. This phenomenon is called the spherical aberration for a lens.

ORAL QUESTIONS

What is a lens? What is it that differentiates a convex from a concave lens? What is the principal focus of a convex lens? Define the focal plane. What is the nature of the image received? What is parallax? Why do you avoid parallax in determining the image position? What is the optical centre of the lens?

Date— EXPERIMENT 99

To plot on a Graph paper the relation between the conjugate foci of the Convex Lens and thence to determine the focal length of the Lens

Theory—The graphical relation between the object and real image distance of a convex lens as given by the form of the equation,

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

represents an arm of a hyperbola. If the origin and the values of the units of co-ordinates on the axes be taken identical, then the equation of a straight line drawn at an angle of 45° to the abscissa is $u=v$. The point of intersection of the hyperbola with the straight line gives,

$$u=v=2f$$

Apparatus—The same as Expt. 97.

Procedure—The same as Expt. 97.

Results—Tabulation as that of Expt. 95 for u and v. Second tabulation for f is not necessary.

A graph paper is taken and with origin as zero suitable equal units are taken along the axes to represent u and v. A straight line is drawn from the origin making an angle of 45° with any one of the axes to cut the curve at a point P. The co-ordinates of this point are measured and found to be equal to $2f$.

Displacement Method

When the distance between the source of light and the screen is considerably large being greater than 4 times the focal length of a convex lens, it can be proved that for a given distance between the source and the screen, there are two positions of the lens for which real images are obtained on the screen.

Let PQ be a linear source of light and a screen at Q_1 be placed at right angles to the principal axis Q_1. Let distance QQ_1 be D (Fig. 198). Let L_1 be one position of the lens for which a real image is obtained on the screen. Let L_1Q be u, then L_1Q_1 = image distance $= D-u$. Thus for the real image due to a convex lens of focal length f.

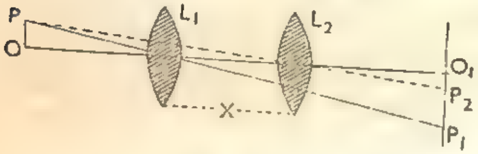


Fig. 198

$$\frac{1}{u}+\frac{1}{D-u}=\frac{1}{f}$$ whence, by simplification $u^2-uD+Df=0$.

This quadratic equation on solution gives two values of u say u_1 and u_2.

$$\text{Let} \quad u_2=\frac{D+\sqrt{D^2-4Df}}{2} \quad \text{and} \quad u_1=\frac{D-\sqrt{D^2-4Df}}{2}$$

Hence there must be two object distances u_1 and u_2 for which real images are obtained on the fixed screen. Suppose $L_1Q=u_1$ and $L_2Q=u_2$.

Then $L_1L_2=u_2-u_1=\sqrt{D^2-4Df}=x$, say

$$\text{Hence} \quad f=\frac{D^2-x^2}{4D} \qquad \dots \qquad \dots \qquad \dots \qquad (1)$$

where x is the distance between the two positions of the lens. When $x=0$, $D=4f$.

It follows from eqn. (1) that for a given value of f, the smaller is the value of D, smaller is the value of x. There is a minimum value of D for which these two positions of the lens coincide, that is x becomes zero. This minimum value of D is 4 times the focal length of the lens; below this limiting value, a real image cannot be formed.

This principle affords a means of measuring indirectly the focal length of the lens by measuring the length of the two images. Let the object of length PQ throw two images of lengths P_1Q_1 and P_2Q_1 for the two positions of the lens, then it can be proved that,

$$PQ^2 = P_1Q_1 \times P_2Q_1 \quad \text{whence} \quad PQ = \sqrt{P_1Q_1 \times P_2Q_1}$$

Date— EXPERIMENT 100

To determine the Focal Length of a Convex Lens by the Displacement Method

Theory—If the distance between the source and the screen be D and if for two positions of a convex lens at a distance x from each other, real images are obtained on the screen, then

$$f = \frac{D^2 - x^2}{4D}$$

where f is the focal length of the convex lens.

Apparatus—Convex lens a source and a screen.

Procedure—Take a pin as the object or a candle flame or more conveniently a cross-wire illuminated by a strong light and place it on a stand at one end of the optical bench (Fig. 199). Fit up a convex lens with a suitable holder on the second stand. In case of a pin serving as the object, place another pin on the third stand. But if the candle flame or illuminated cross-wires be the object, a screen consisting of a piece of white unglazed paper stretched upon a metal ring is to be mounted upon the third stand. Bring the stands as close as possible and make the source, centre of the lens and the screen co-axial (Expt. 197). Now slide away the screen at a fair distance.

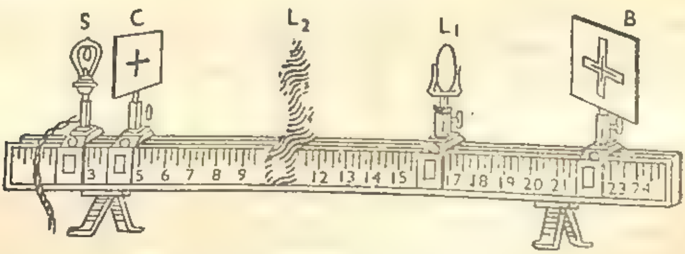


Fig. 199—Displacement Method

Then slide the stand for the lens at a suitable distance from the source so as to get sharp real image on the screen. If for no position of the lens real image is obtained, the screen is to be moved further away. In case of pins, shift the lens by a small distance and try to remove the parallax between the image of one pin and the

other. At a certain position of the lens there would be little or no parallax.

When a real image is obtained on the screen, read the position of the lens from the optical bench. If the lens is nearer the source, gradually slide it on its stand towards the screen until another sharp real image is thrown on the screen. Read this positions of the lens again. The difference of readings gives the displacement of the lens x. Read also the positions of the source and the screen. With an index rod, make the index correction between the source and the screen, after removing the lens. Add index error to the difference of readings of the position of the source and that of the screen, which gives D. Take three sets of observations changing the value of D each time and find the focal length in each case. Find the mean of these observed focal lengths. In case of pins, follow the same procedure; but find the image position always by avoiding parallax. The index error between the two pins should be taken into consideration. This experiment with pins is a bit tedious one, but the illuminated cross-wire method is very convenient.

No. of Readings	First position of Lens	Second position of Lens	Difference x	Position of Source	Position of Screen	Difference	Index error	D	Focal Length
	cm.	cm.	cm.	cm.	cm.	cm	cm.	cm.	cm
1.	36·9	61·4	24·5	96·9	4·5	92·4	−5·0	87·4	20·1
2.	...	...	...		...	...	...	...	20·0
3.	18·3	64·2	45·9	96·9	...	...	...	106·3	20·4

Discussion—In order to carry out the displacement method, the optical bench must be longer than four times the focal length of the lens under examination. If the distance between the source and the screen is made much greater than $4f$ x becomes large and for one position of the lens, the image is too small and for the other position too large. It is then a matter of difficulty to remove parallax of the image specially when it is large. Hence for an accurate determination of f, x should not be taken too large.

Oral Questions

What is a displacement method? Why do you get a more magnified image for one position of the lens? What is parallax? What is index correction? Is index correction necessary for the lens stand? Is there any minimum length on a optical bench for which a real image may be obtained with a convex lens? What is called the power of a lens? What is a dioptre?

Refractive Index of the Material of the Lens

The refractive index μ of the material of the lens, its focal length f and its radii of curvature r_1 and r_2 are connected by an equation—

$$\frac{1}{f}=\left(\mu-1\right)\left(\frac{1}{r_1}-\frac{1}{r_2}\right)$$

For a double convex lens f and r_1 are negative in sign and further for an equi-convex lens $r_1=r_2=r$, say

Hence, $\frac{1}{f}=\left(\mu-1\right)\left(\frac{1}{r_1}+\frac{1}{r_2}\right)=\left(\mu-1\right)\frac{2}{r}$.

$$\therefore\quad \mu=1+\frac{r}{2f}.$$

On determining the focal length of a lens and on measuring its radius of curvature with a spherometer, μ can be calculated.

Combination of thin Lenses in Contact

Let L_1 and L_2 be two thin lenses of focal lengths f_1 and f_2 placed *in contact* (Fig. 200). Let a point source of light O placed at a distance u from the combination on the principal axis have its image at P at a distance v_1 due to the first lens of focal length f_1. Then according to the general equation of the lens,—

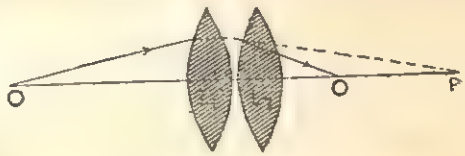


Fig. 200

$$\frac{1}{v_1}-\frac{1}{u}=\frac{1}{f_1} \qquad \dots \quad (1)$$

Now in so far as the refraction at the second lens L_2 is concerned P acts as the virtual source at a distance v_1. Let the final image be formed at Q at a distance v from the combination. Hence for the second lens of focal length f_2—

$$\frac{1}{v}-\frac{1}{v_1}=\frac{1}{f_2} \qquad \dots \quad (2)$$

Combining equations (1) and (2), we get

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f_1}+\frac{1}{f_2} \qquad \dots \quad (3)$$

A single lens, which being placed, produces an image of an object at the same place and of the same magnification as that due to the combination of lenses is known as an *equivalent lens*. Hence if F be the focal length of such an equivalent lens.

$$\frac{1}{F}=\frac{1}{v}-\frac{1}{u}=\frac{1}{f_1}+\frac{1}{f_2} \quad \dots \quad (4)$$

This is the general equation for two lenses in contact. If the two lenses be convex then both have negative focal lengths and the focal length of the combination are negative, whereas if one lens be convex and the other a concave then one focal length is negative

while the other is positive. Then the reciprocal of the focal length of the combination is the difference of the reciprocal of their focal lengths. The nature of the combination, either a convex or a concave, is determined by the algebraic sign of the equivalent focal length. This method is sometimes adopted in determining the focal length of a concave lens.

Date—

EXPERIMENT 101

To Determine the Focal Length of a Concave Lens by the Combination Method

Theory—If the focal length of a combination of a convex and a concave lens be—F and if the focal length of the convex lens alone be $-f_1$, then the focal length f_2 of the concave lens is given by the relation,

$$f_2 = \frac{f_1 F}{F - f_1}$$

Apparatus—An optical bench, a combination of a convex and a concave lens, a source of light and a screen or two pins.

Procedure—Take as the source of light either a candle stick or a pin P_1 and mount it upon a stand at one end of the bench. Make a combination of the convex and the concave lenses in a suitable holder and place them on the middle stand. In case of flame as the object place a paper screen on the third stand or if a pin be the object, place another similar pin on this stand (Fig. 201). Find the focal length of the combination by U—V method or by displacement method (vide Expt. 97 or 100). Then take the concave lens from the holder so that the convex lens remains on the stand. Find the focal length of this lens in a similar way. Then from the formula find the focal length of the concave lens.

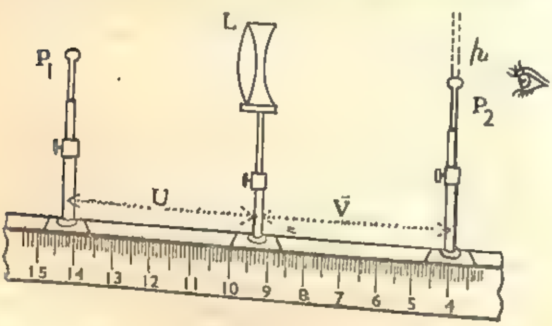


Fig. 201

Results—Tabulate the results for the combination and for the single convex lens as in U—V or displacement method.

Discussions—In order that the combination of lenses may behave as a convex lens, the focal length of the convex lens must be shorter than the focal length of the concave lens. To carry out this experiment an optical bench of longer type is necessary.

ORAL QUESTIONS

What sort of image do you get in a concave lens? What is the difference between a convex and a concave lens? Why don't you apply the direct $u-v$ method to find focal length of a concave lens? What is the function of the convex lens used in the combination method? Does any convex lens combine with a concave lens for the combination method; if not why?

Date—

EXPERIMENT 102

To Measure the Refractive Index of Liquid with a Plane Mirror and Convex Lens

Theory—If the focal length of the convex lens be f_1 and when that lens is placed upon a plane mirror with some liquid in between the focal length of the combination be F. then the focal length f_2 of the plano-concave liquid lens, so formed, is given by,

$$f_2 = \frac{f_1 F}{F - f_1}$$

Again if μ be the refractive index of the liquid of which the lens is formed, r be the radius of curvature of the lower surface of the convex lens which is evidently the upper surface of the liquid lens,

$$\text{then } \mu = 1 + \frac{r}{f_2}.$$

Combining the two equations,

$$\text{we get, } \mu = 1 + \frac{r(F - f_1)}{f_1 F}.$$

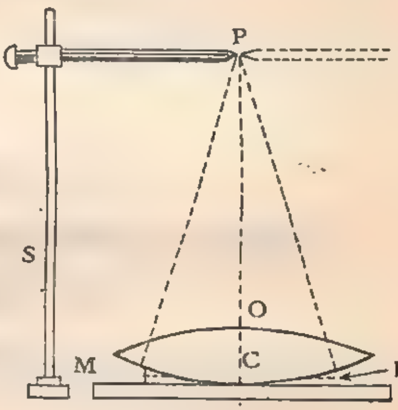


Fig. 202

Apparatus—A plane mirror, a convex lens, a small quantity of a transparent liquid, a vertical stand, a pin, spherometer.

Procedure—Place the plane mirror horizontally on a table and put the convex lens on the mirror. Fix up a long pin P on the adjustable vertical stand S in a manner as shown in Fig. 202. Now find the focal length f_1 of the lens in accordance with the directions as given in Expt. 99. Take at least *three* sets of readings for the focal length and find the mean. Then put a few drops of liquid on the plane mirror and place the convex lens upon it. The combination behaves as a plano-convex lens. Take also *three* sets of readings for the focal length of the combination and find the mean focal length F.

Then measure with the spherometer the radius of curvature of the lower surface of the convex lens as given in Expt. 7. Take *five* sets of readings and obtain the mean value.

Results—

Tabulation as shown in Expts. 99 and 7.

Hence $\mu=$.........

Discussions—Similar to Expt. 99. When the liquid put is extremely small, it spreads over a small area on the mirror and so the aperture of the combined lens is small. In that case it is difficult to examine the parallax between the pin and its image. In viewing the image, the eye of the observer should be placed well behind to see the image clearly.

ORAL QUESTIONS

Why do you use a plane mirror in finding the focal length of the convex lens? Can you do this experiment using a spherical mirror instead of a plane mirror? Why is the focal length increased when liquid is used? Can you find the refractive index of a coloured liquid by this method? Is it possible to find the refractive index of chinese black ink; if not why?

Date—

EXPERIMENT 103

To Measure the Focal Length of a Concave Lens by the Parallax Method (Plane Mirror Method)

Theory—The image produced by a concave lens is always virtual in nature and is given by the relation,

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

when u = object distance, v = image distance and f = focal length, all measured from the principal point of the lens or approximately from the nearest surface of the lens.

The position of the virtual image with a concave lens may be conveniently determined by coincidence of another similar image produced by a plane mirror placed suitably.

Apparatus—An optical bench, a concave lens, two hair pins, a plane mirror.

Procedure—Mount a long hair pin P on a stand at one end of an optical bench. Fix a concave lens L on another stand at the middle of the bench. Adjust its height so that the head of the pin and the top of the lens are nearly on a horizontal plane (Fig. 203). Mount a small rectangular plane mirror M on a third stand in front

of the lens such that the upper horizontal edge of the mirror is approximately at the central part of the lens and its reflecting surface is away from the lens. Place another hair pin Q upon a fourth stand in front of plane mirror at the same height as that of the first pin.

Place your eye behind Q and observe in a direction along P. You would be able to see the image of Q reflected in the plane mirror some where on the back side of the mirror. If this image appears to be much deviated from the bed of the optical bench, turn the plane mirror along its stand as axis by the required amount to bring the image on the bed. You would also see the refracted image of P due to the lens, which would also appear to be a bit smaller in size but erect and formed some where behind the lens. Now adjust the height of your eye, so that you are able to see the *lower half* of the image of Q and the *upper half* of the image of P *along a vertical line*. This alignment of the images, you can do by *slightly* tilting the plane mirror along vertical axis.

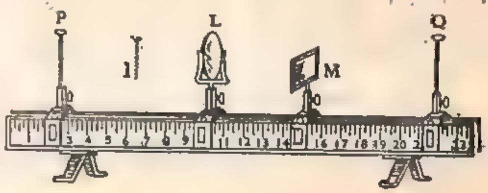


Fig. 208

When this is done, move your eyes slowly left and right and observe the relative change of position of *these two halves* of the images. If there is parallax, try to remove it by sliding the position of the mirror or the pin P on the optical bench. Finally get the position for which there is no parallax between the two halves of the images. Then the image position of the second pin due to the plane mirror is coincident with the image position of the first pin due to concave lens.

Now read from the optical bench the position of the first pin P and call it a cm. Read the position of the concave lens and call it b cm. The difference of these two readings gives apparent object distance. Take the reading of the plane mirror, call it c cm. Also read the position of the second pin Q, which is say d cm. Then $2c-(d+b)$ gives the distance between the image of Q and the concave lens, which is evidently the apparent image distance v_1. Change slightly the position of the pin P and take another series of readings for u_1 and v_1. In this way, by changing the position of the object every time, take four or five sets of readings. Finally make the index corrections for object and image distances and get the true object and image distance u and v.

Then from the formula $f=\dfrac{uv}{u-v}$ calculate from each set the focal length of the lens. Thence find the mean focal length.

Results

Index correction for u =

Index correction for v =

No. of readings	Apparent object distance	Index correction	Real object distance	Distance of second pin & plane mirror	Distance of concave lens & plane mirror	Apparent Image Distance	Index correction	Real Image distance	Focal length	Mean Focal length
	$a \sim b = u$	$\pm m$	$u = u_1 \pm m$	$c \sim d$	$b \sim c$	$v_1 = 2c \sim (d+b)$	$\pm n$	$v_1 \pm n$	$\frac{uv}{u-v}$	f
	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
1.										
2.										
3.										
4.										
5.										

Discussion—The height of the plane mirror is to be so adjusted that half the image of the pin is seen reflected in the plane mirror. The upper half of the image is due to refraction of the other pin in the concave lens. The upper edge of the mirror is to be straight and horizontal.

ORAL QUESTIONS

What is the nature of the image in a concave lens? What is the function of the plane mirror in this experiment? Why do you avoid the parallax between the image due to the plane mirror and that due to the lens? Can you apply a similar method in finding the focal length of a convex lens?

Magnifying Glass

If an object PQ is placed within the focal length of a convex lens (Fig. 204), a virtual, erect and magnified image is seen by the eye placed close behind the lens. A convex lens used in this manner is called a *magnifying or reading glass.*

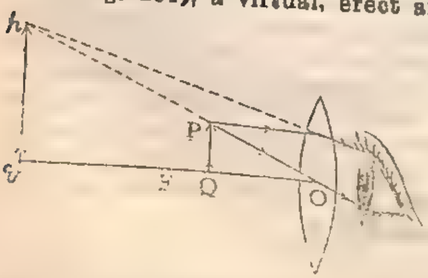


Fig. 204

The apparent size of an object depends upon the angle subtended by the object at the eye of the observer. If the object moves closer to the eye, the angle subtended increases and so the object appears larger. To every unaided eye there is a minimum distance at which an object appears

most distinct. This is known as the *least distance of distinct vision.* If the object is brought still closer, the apparent size increases but the object becomes indistinct.

To see the magnified image most clearly, the object is to be placed at such a distance from the lens that its virtual image is formed at the least distance of distinct vision, the eye being placed very near the lens. Let OQ $=u$, OI $=v$, D = least distance of distinct vision, f = focal length.

Then magnification $m=\frac{v}{u}=\frac{D}{u}$.

But as the image is virtual, v is positive and f of a concave lens is negative,—

$$\therefore \quad \frac{1}{v}-\frac{1}{u}=\frac{1}{f} \quad \text{whence} \quad \frac{v}{u}=1+\frac{v}{f}=1+\frac{D}{f}.$$

Date—

EXPERIMENT 194

To Determine the Magnifying Power of a Lens

Theory—The ratio of the angle subtended to the eye by the image of an object at the least distance of distinct vision to the angle subtended to the eye by the object at the same distance, is called the angular magnification of the lens. If f denotes the focal length of a lens and D the least distance of distinct vision then the magnification m is given by

$$m=1+\frac{D}{f}.$$

Apparatus—A convex lens, a metre scale, one rectangular or square slit and a vertical stand.

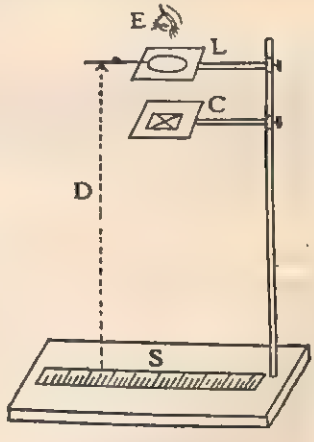


Fig. 205

Procedure—Place a metre scale S on the table by the side of a vertical stand. (Fig. 205). Fix the lens holder L to an adjustable clamp. Look at the scale vertically downwards and examine from which height, you can see the graduations of the scale best without straining your eyes. This height D is the least distance of distinct vision. Measure this height with another metre scale and clamp the lens holder with the lens at this distance from the horizontal scale. For a normal eye, this distance would be between 25 to 30 cm. Place a rectangular slit, about 1 cm. long on another stand C in between the scale and the lens, so that the length of the slit is parallel to the length of the scale. Now place

the eye very near the lens, adjust the height of the slit so that a very clear image of the slit is observed. Use one eye to see the image while the other eye see the scale directly. The slit is found to cover a certain length of the scale. Measure this length with eye estimation. Take three readings of this length.

Now measure the focal length of this lens by the plane mirror and pin method. Then compare with the usual formula for magnification, with the result obtained.

Results—

Least Distance of Distinct Vision D = 25 cm.

No. of readings	Length of slit *a* cm.	Length of image *b* cm.	Magnification *b/a*	Focal length *f* cm.	Magnification $1+\frac{D}{f}$	Percentage Difference
1. 2. 3.						

Discussions—The distance of the eye from the lens controls the observed magnification. Hence the eye should be placed as near the lens as possible. A preliminary test should be done to fix up the least distance of distinct vision which varies slightly with different persons. It would be found that distinctness of the image increases, if between the lens and the eye an opoque screen with a small circular hole is interposed.

Oral Questions

Define magnification of a lens. What is the distinction between linear and angular magnification? What is the least distance of distinct vision? Does is differ with different persons? What is the reason that a myopic or hypermetropic eye has its least distance of distinct vision changed?

Simple Telescopes

In principle, an astronomical telescope consists of two convex lenses,—one, called the *objective* having a large focal length and aperture and the other, called the *eye piece* having a small focal length and aperture. The function of the objective is to produce a real, inverted and diminished image of a distant object on or very near to its focal plane and the function of the eye-piece is to magnify this image by producing its virtual image so that the final image may be seen according to convenience either at the least distance of distinct vision or at infinity. (Vide Basu & Chatterjee's Intermediate Physics Vol. II. Light. Chap. VI).

Chromatic Aberration—In practice, if we produce a real image of a white object, say, an electric lamp, by a single convex lens and receive it on a white screen, then no carefully examining with a magnifying glass the image formed, we can observe the following phenomena.—

The edges of the image are fringed with colours of which red and blue predominate. The larger is the image or shorter is the focal lenth of the lens, the more pronounced are the colours. The edge colours can be seen with naked eyes when the object, say a lamp, is placed near the focus of the lens, so that a large image of the lamp is projected on a distant wall. So we come to the conclusion from this fact that the image of a white object due to a convex lens does not appear to be an exact copy of the object, or the image suffers from a coloration effect. This defect is called the chromatic aberration of the lens and is due to two refracting surfaces of the lens acting as two sides of a prism which disperses white light into various colours.

This chromatic defect of the image is naturally smaller in a convex lens of larger focal length. To verify this effect, concentrate the light from a distant electric lamp to a sharp image first by means of a convex lens of focal length, say 30 cm. and examine the image by a moderately good magnifying glass. Then focus the image of the same lamp by another convex lens of say, 10 cm. focal length and examine the image in a similar way. The coloration in the latter case is more prominent. So any single convex lens would have this chromatic defect more or less. Such a single lens used as the objective of a telescope and turned towards a star would distort the image by undesirable colorations. Now two lenses, one covex of shorter focal length and of crown glass and another concave lens of longer focal length and of flint glass, may be combined together so that the chromatic defect of one may be compensated by the other. The combination remains as a convex lens and is free from chromatic aberration. This is called an achromatic combination and is used in all types of telescopes and other optical instruments. To verify this, fit up a telescope objective on an optical bench and get a sharp image of a distant white object. Examine the image with an eye-piece carefully. You would find very little coloration of the image. (For details vide Basu & Chatterjee's Intermediate Physics, Light. Chap. VII).

Spherical Aberration—If we use a convex lens of a large aperture to produce an image of a point surce of light, the image is no where a point. The best image is a small illuminated disc. This defect in the image formation of lenses is called *spherical aberration*. The distortion of the image is due the fact that in case of a lens, its different parts relative to its centre have got *slightly different* focal lengths. When light from a point object is refracted through the lens, the different parts of the lens bring the images to different points affecting the clarity of the image formed. For a convev lens, considering different circular annular zones on its surface, the focal length becomes shorter and shorter as we move to outer zones. This defect in image formation can be minimised by placing an opaque screen with a small circular hole in front of the lens. Such a screen is called a stop, the function of which is to reduce the

refracting zone of the lens. Light is then refracted by the central portion of the lens and such distortion of the image is reduced to a very small amount so as to be imperceptible.

To demonstrate this defect, place a convex lens in its holder on the stand of an optical bench. Fit up a screen with an adjustable round slit, called an iris diaphragm, just in front of the lens. Now take a metal plate with a round hole about quarter inch in diameter on another stand and illuminate this hole by some strong coloured light. Get the real image of this aperture on a white screen. With the aperture of the diaphragm wide open, you can clearly observe the distortion at the edge of the image. Now gradually reduce the size of the aperture. Now you would see that the image is becoming less bright but more well defined.

The spherical aberration increases very rapidly with lenses of shorter focal lengths. Conseqently, the larger is the magnifying power of a lens, the larger is the distortion of the image due to spherical aberration. In astronomical telescopes, the magnification of the eye-piece is to be made large, usually between 10 and 20, and so the spherical aberration in the eye-piece cannot be reduced to an inappreciable degree by a single lens and a stop. Usually two lenses, each one a plano-convex of some definite focal lengths and placed at some definite distances, serve the purpose of an eye-piece. Such eye-pieces are designed to have minimum effects of spherical and chromatic aberrations.

Date—

EXPERIMENT 105

To Study the Principle of an Astronomical Telescope

Theory—Two convex lenses of focal lengths F and f, placed co-axially at an approximate distance $F+f$ from each other, show the principle of a telescope. The convex lens of larger focal length is the objective and the other one is the eye-piece and the overall magnification for incident parallel rays is F/f.

Apparatus—One convex lens of focal length 30 to 40 cm. and of a diameter of about 10 cm. Another convex lens of focal length 5 to 10 cm. and almost of the same diameter, an opaque screen with a round hole of diameter of about 5 mm., an adjustable round aperture (an iris diaphragm), another ring fitted with cross-wires, an optical bench with 5 stands.

Procedure—Place the lens L_1 of larger focal length in a ring holder and mount it on a stand almost at the end of a bench (Fig. 200). Leave aside the second stand for the present and fix up a pin on the third stand at the same height as the lens. Now stand about 50 to 60 cm., behind the lens and look through the lens to a *distant* object, say a tree, through the window of the

laboratory. An inverted real image of the object would be seen. Now shift the position of the pin and make it coincident with the image by removing parallax. The pin very approximately coincides with the focal plane of the lens.

Now clamp both the stands to the optical bench and replace the pin of the second stand by the ring S carrying the cross-wires. Mount the lens of the shorter focal length to the third stand at the same height as the ring. Then gradually slide back this lens with your eyes close behind it until a very clear magnified image of the cross-wires is seen. At this position you would also be able to see the inverted image of the distant tree. Slightly move this lens backward or forward and permanently set it for the position at which the image of the tree is sharpest. Then slightly reset the position of the cross-wires removing the parallax between it and the image. Now the image and the cross-wires are very nearly at the focal plane of the objective.

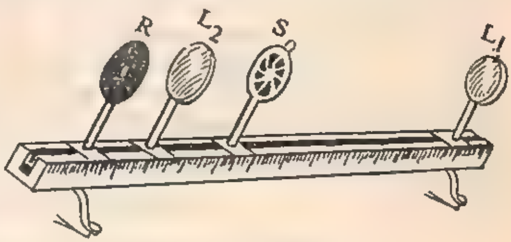


Fig. 206

Then mount the round aperture R on the fourth stand and place it very near the eye-piece and look through the aperture. You would see through it the clear image of the cross-wires and the tree at the central part with a hazy background all round it. This is due to the fact that the field of view here is larger than the area over which the image has been cast. Now slowly shift the position of the aperture and at the same time look through it. You would see that the field of view is gradually growing smaller and the hazy parts are vanishing continuously. At a certain position of the aperture, the field of view has entirely covered the image area and the image appears brilliant. This is really the field of view that is wanted in a telescope and a small aperture is placed in this position which is called the eye-ring.

Observe the image carefully through the eye-ring. The edges of the field of view appear fainter and coloured and any image formed near the edge appears slightly curved. Now fit up the iris diaphragm on the third stand just in front of the eye-piece and slowly lessen the aperture of the iris-diaphragm. Observe that field of view is growing smaller, the image as a whole is growing more distinct and less curved. Hence by lessening the effective aperture of the eye-piece, the effect of spherical aberration can be minimised.

Observe through the eye-ring and adjust the position of the of the eye-piece. Repeat the observation three times and measure this distance. Lastly dismantle the arrangement and measure by any method the focal lengths of the objective and the eye-piece.

Results—

No. of readings	Distance between objective and Eyepiece	Focal length of objective F	Focal length of Eyepiece f	Magnification F/f
	cm.	cm.	cm.	
1.				
2.				
3.				

Discussions—All the different parts composing the telescope must be placed co-axial to have the desired effect. The cross-wires should be made of unspun silk thread and should be as thin as possible. The magnification of a telescope for infinitely large distance is F/f, but for nearer object it is greater.

Date—

EXPERIMENT 106

To Study the Principle of a Galilean Telescope (Opera Glass)

Theory—One convex lens of focal length F, serving as the objective placed co-axially with another concave lens of focal length f, serving as the eye-piece and placed at an approximate distance $F-f$, constitutes a Galilean telescope of magnification F/f.

Apparatus—One convex lens of 30 to 40 cm. focal length, one concave lens of 10 cm. focal length, one iris diaphragm, optical bench and one pin.

Procedure—Mount the convex lens on the first stand of the optical bench and with your eye at about half a metre from the lens observe through it the inverted image of a distant object. Fix up the pin on a second stand and move it to a position such that there is no parallax between it and the image. The position of the pin is evidently the focal plane of the lens. Measure the distance between the lens and the pin, which is the focal length of the lens.

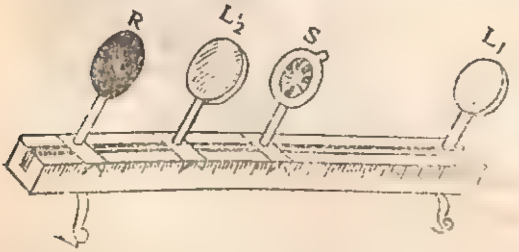


Fig. 207

Read the position of pin and remove it. Mount the concave lens L_2 on a third stand and make the height of the two lenses same (Fig. 207). Now place the concave lens 2 or 3 cm. away from the position of the pin on the side of the convex lens. Place the pin on the fourth stand and again remove the parallax between it and the final

real image through the concave lens of the distant object. Then with reference to the concave lens, the object distance is the difference of readings of the position of th original pin, that is the focal plane of the convex lens and the position of the concave lens. The object before the concave lens being the real image due to the convex lens, is called the virtual object and the object distance is taken to be negative. The image distance is that between the concave lens and the pin. Then from the formula for virtual object due to concave lens calculate the focal length. Take two or three readings for the object and image distances and hence find the mean focal length of the concave lens.

Now place the concave lens within the focal length of the convex lens so that the focal planes of both the lenses coincide and observe through the concave lens. An *erect* image of a distant object is seen through the combination when eye is relaxed. This proves that the length of the telescope so formed is $F-f$. For clearest vision the eye-piece is to be shifted a few millimetres towards the convex lens when the final image is formed at the least distance of distinct vision. See that for any position of the cross-wires on the optical bench, it does not come in focus. Therefore, such a telescope cannot be fitted with cross-wires. Observe also that the field of view in this case is smaller than that of the astronomical telescope. This is because the field of view is formed in a divergent beam from the eye-piece. For a very clear vision an

No. of readings	Distance between Objective and Eye-piece	Focal length of Objcotive	Focal length of Eyepiece	Magnification F/f
	cm.	cm.	cm.	
1. 2. 3.				

eye-ring is to be fitted just behind L_2. To minimise spherical aberration an iris-diaphragm is to be put between L_2 and L_1.

Discussions—All the components of the telescope should be placed co-axial. A disadvantage of this type of telescope is that the field of view is small. Hence a prism binocular is more preferable to a Galilean form of telescope. A cross-wire cannot be fitted with it.

ORAL QUESTIONS

What is the use of a telescope? What are the functions of the objective and the eye-piece? Why is the focal length of the objective made larger than that of the eye-pice? What would happen if the positions of the lenses are interchanged? What is the function of the cross-wires and where is it placed? What is the field of view and upon what factors does it depend? Why do you see a bluish tinge at the edge of the field of view and how can it be corrected for? What is spherical aberration of the image and how can it be minimised in your telescope? Compare the advantages and disadvantages of the astronomical and Galilean telescope.

Compound Microscope

As the purpose of a compound microscope is to magnify greatly a small object, this magnification is done by two instalments The object is placed *a little beyond* the focal plane of the objective lens. so that an inverted real and large image is formed on the other side of the lens at a considerable distance from it. The image distance being many times larger than the object distance, the magnification of this image is considerable. In a good microscope this magnification may be as high as 40 to 50. The focal length of the objective lens in such a case as 1 cm or even less. The image due to the objective is formed *just within* the focal length of the eye-piece, so that a magnified virtual image of this image is formed on the same side of this lens. This second magnification may be 8 to 10 so that the over-all magnification of a very good microscope is 400 to 500. The magnification or ordinary laboratory microscope is less than 100. In general the shorter is the focal length of the objective, the larger is the magnifying power of the microscope. (For the principle and working of a microscope, vide Basu and Chatterjee's Intermediate Physics. Vol. II. Light Chap. VI.)

Now, if a single convex lens of focal length 1 cm. or less be used as the objective of the microscope, the lens would show defects of the image in form of colours (chromatic aberration) and distortion (spherical aberration) to such a degree that it would be of no advantage to magnify the image. For this reason the objective is made of a number of lenses of different samples of glass and of different focal lengths, all put together co-axially. The lenses are arranged in such a way that the defects of the image arising out of one lens or preceding lenses are partially or wholly corrected by the next lens or succeeding lenses. The objective of a goad microscope for viewing purposes consists of 6 lenses of which four are convex and two concave. For photographing minute objects a microscope objective should have a greater number of lenses.

The eye-piece of a microscope is like that of telescope except that a greater care is made for its construction to minimise or eliminate the effects of chromatic and spherical aberration if present in the image due to objective.

Date—

EXPERIMENT 107

To Study the Principle of a Compound Microscope

Theory—One convex lens of short focal length f serving as the objective together with another convex lens of medium facal length F placed co-axially at a suitable distance illustrates the model of a compound microscope. If a small object is placed at a distance u from the objective, then the magnification of the image seen at the least distance of distinct vision D is given by,

$$\frac{v}{u}\left(1+\frac{D}{F}\right)=\frac{f}{u-f}\left(1+\frac{D}{F}\right)$$

where v is the image distance from the objective.

The distance between the two lenses is $\frac{uf}{u-f}+\frac{DF}{D+F}$

Apparatus—One convex lens of focal length 5 cm., another convex lens of focal length 10 cm., an iris diaphragm, one round aperture of diameter 5 to 10 mm., a small object such as a pin point, ring with cross-wires, a vertical stand with 5 adjustable clamps.

Procedure—Roughly determine the focal length of the two lenses supplied to you by holding them against the sun or a distant object and receiving the image on a piece of paper. The distance from the lens to the paper gives in each case an approximate focal length. Put a small object O on a piece of paper and place it on the base of the stand and mount the convex lens of shorter focal length on the second stand. Now adjust the position of this lens such that the distance between these two is about 1 cm. greater than the focal lenth of the lens. Observe from a height on the other side of the lens when an inverted magnified image is seen. Fix on a third stand the ring with cross-hair at such a position that there is no parallel between image of the object and this one. So this is the position of the image. Now measure the object distance u and the corresponding image distance v.

Then place the iris diaphragm on this stand just behind the ring with its aperture wide open. Mount the convex lens of larger focal length on the 4th stand and adjust its distance so that the cross-hair appears distinct and magnified. The image of the object also at this position appears magnified. A slight readjustment of the position of the cross-hair may be necessary to remove the parallax between it and the image. Place the eye ring R on the 5th stand and adjust its position with eye close behind it so that the image covers the field of view. The image looks very distinct but the edges of the image appear slightly curved. This is due to the spherical aberration of the lenses. Now shorten the aperture of the iris diaphragm when the distortion of the image becomes less. Illuminate the object strongly with white light, when the edges of the image appear coloured. This is due due to chromatic aberration.

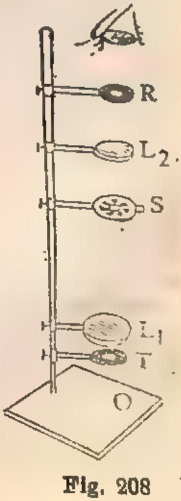


Fig. 208

Now take out the object glass, iris diaphragm and the eye-ring. Remove the cross hair to the stand carrying the eye-ring. With the help of the pin as the object and cross-hair as the image screen, find by conjugate foci method the focal length of the eye-lens, in a manner as given by Expt. 97.

Least distance of Distinct Vision D=.........

No. of Readings	Object distance from Objective u	Image distance from Objective v	Focal length of Eyepiece F	Magnification of Objective v/u	Magnification of Eyepiece $1+\frac{D}{F}$	Over all Magnification $\frac{v}{u}\left(1+\frac{D}{F}\right)$
	cm.	cm.	cm.			
1.						
2.						
3.						

Discussions—The same as in peceding Expt.

Photometry

The apparatus by which a comparison of brightnesses of two sources of light is made is called a Photometer.

The *intensity of illumination* or simply *illumination* at any point of a surface is the amount of light falling in one second on unit area round the point. For a given surface, the intensity of illumination depends upon the inclination of the rays illuminating the surface. The foot-candle is the practical unit of intensity or illumination and is measured by the amount of light faling on a unit white surface of a sphere of one foot radius due to standard candle burning at its centre. Sometimes the brightness of a surface is measured in terms of a lumen which is the quantity of light failing per second on a square foot of white surface placed normal to the rays of light at a distance of one foot from a standard candle; therefore one foot-candle is one lumen per square foot.

The brightness of a source of light apparently depends upon the amount of light energy entering the eye per second from the source and this quantity is proportional to the amount of light energy given out by the source per second. The *luminous intensity* or the *illuminating power* of a source of light is the quantity of light that falls in one second on a unit surface placed at a unit distance from the source, light falling perpendicularly on the surface. The candle power is the unit in which the illuminating power of a source is expressed. It expresses the ratio of iluminous intensity of a given source of light to that of a standard candle. The standard candle is a candle of spermacetl wax $\frac{7}{8}$ inch in diameter. weighing six to the pound and burning at the rate of 120 grains per hour. The luminous intensity of such a standard candle is found to change slightly with the length of the wick and other factors. It is now replaced by the Vernon Hercourt pentance lamp, which has a luminous intensity of 10 times the standard candle when it burns in air at 760 mm. pressure containing 0·8% water vapour.

When the source of light is an extended one, every point of the surface acts as an independent source of light. The *intrinsic luminosity* or *brightness* of such a surface is defined to be the candle power per unit area of the surface.

Principle of Photometry

If two sources of illuminating powers P_1 and P_2 paoduce as equal intensity of illuminations at two adjacent portions on a screen and if the distances of the sources from the screen be d_1 and d_2 respectively, then

$$\frac{P_1}{d_1^2}=\frac{P_2}{d_2^2} \text{ whence } \frac{P_1}{P_2}=\frac{d_1^2}{d_2^2}$$

Hence the illuminating powers of two sources are directly proportional to the squares of their distance from the screen at which they separately produce the same intensity of illumination.

It should be noted that the sources to be examined should emit light of a similar colour for a direct comparison of intensity to be possible. A lamp giving blue illumination cannot be *directly* compared with another lamp giving red light.

Date— **EXPERIMENT 108**

To Compare the Candle Powers of two Lamps by Bunsen's Greased spot Photometer

Theory—If two lights of candle powers L_1 and L_2 at distances d_1 and d_2 from a greased spot screen produce equal illumination on the screen, then

$$\frac{L_1}{L_2}=\frac{d_1^2}{d_2^2}$$

Apparatus—A Bunsen's photometer and two sources of light.

A Bunsen's photometer consists of a long and uniform horizontal bed having a scale on one side resembling an optical bench (Fig. 203). Tnere are three vertical stands which can side over the bench. The middle one carries an upright provided with a ring at its top. Tne ring carries a sheet of white unglazed paper with an oil or greased spot near about its middle. The two sources of light, whose illuminations are to be compared, are placed upon two other stands of the bench.

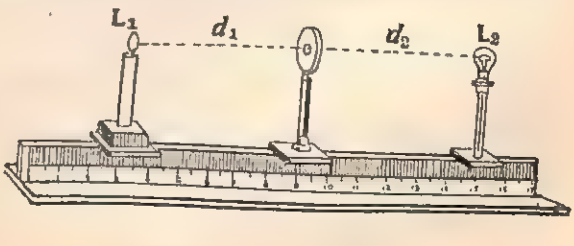


Fig. 203—Bunsen's Photometer

Procedure—Place the two lamps on the photometer stands and adjust them to be in line with the greased spot. Each light produces its illumination on one side of the spot. Now observe the greased spot If the brightness on the two sides be unequal then looking from the side of greater brightness the spot will appear to be shaded. Now shift the middle stand to a particular position where the greased spot appears to be least visible. Both the sides of the spot are then equally illuminated. Measure the distances d_1 and d_2 of the lamp stands from the middle stand. For a given position of one lamp, read to positions of the other lamp *viz.*, when it is approaching and when receding. The mean of the two readings gives the true position of this lamp. Take three or four sets of readings.

Results—

No. of observations	Position of L_1	Position of screen	Length d_1	Position of L_2	Length of d_2	$\frac{d_1^2}{d_2^2}$	Mean
	cm.	cm.	cm.	cm.	cm.		
1.	6.4	18·4	12·0	62·6	44·2	·074	
2.	6·4	18·4	12·0	62·6	44·2	·074	·074
3.	...	...	...	...	...	...	
4.		...	...	...	...	...	

Discussions—The lamps to be compared should be such that the ratio of the candle powers be not very large or too small, because when d_1 and d_2 are very much unequal a small error in measuring any one of them introduces a large error in determining their ratio.

Date—

EXPERIMENT 109

To Compare the Candle powers of two Sources by Rumford's Photometer

Theory—If d_1 and d_2 be the distances of two sources of candle powers L_1 and L_2 from an opaque screen producing an equal illumination upon it, then

$$\frac{L_2}{L_1}=\frac{d_2^2}{d_1^2}$$

Apparatus—Rumford's photometer, a metre scale and two sources of light.

A Rumford's photometer consists of a long horizontal table on

which a vertical wooden board is placed (Fig. 210). On the front

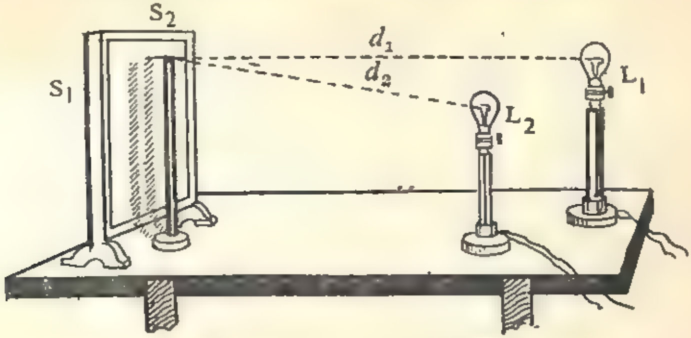


Fig. 210

face of the board a piece of white paper is pasted. Just in front of the board an opaque rod is placed vertically.

Procedure—The two sources of light are placed on the table so as to throw two images (shown by shaded parts) of the rod side by side on the paper screen. It is evident from the Fig. 210 that the shadow of the rod cast by the light of candle power L_2, is illuminated by the light of power L_2 and vice versa. The two lights are so adjusted that the two shadows are equally illuminated. For the success of the experiment, the two shadows should be as near to each other as possible. The intensity of illumination for both the lights on the screen is, therefore, equal. The distances d_1 and d_2 are measured with a metre scale. A number of readings for both d_1 and d_2 is taken and the ratio of d_1^2 to d_2^2 is calculated in each case.

Results—

No. of observations	Distance d_1		Mean d_1	Distance d_1	$\frac{d_1^2}{d_2^2}$	Mean
	Approaching	Receding				
	cm.	cm.	cm.	cm.		
1.	66·4	96·8	6·6	52·6	1·6	
2.	...		...	...	...	1·6
3.	...	...	...	...	...	
4.	..	...	...	..	...	

Discussions—The same as the preceding experiment. The source L_2 supplied is a 20 C.P. electric lamp. Hence L_1 has got a candle power 1·6 times larger *i.e.* 32 C.P.

ORAL QUESTIONS

Define intensity of illumination and illuminating power. What is the unit of illuminating power? What is the general principle upon which a comparison of illumination of two sources depends? What is the idea behind a greased spot or a Bunsen's photometer? What is the function of the stick before the screen in Rumford's photometer? Is it essential that the sources to be compared should be placed almost co-axially?

CHAPTER VI

EXPERIMENTS ON SOUND

In some musical instruments such as clarionet, flute, etc. each containing a hollow pipe, notes are produced due to the stationary vibration of air column within the hollow pipe provided. Each instrument has got either a lip or a reed at one end and when air is forced through this end by blowing, some sort of air vibration is set up here. Such a vibration passes through the hollow of the instrument to the other end and is successively reflected back. These two systems of waves are superposed and stationary waves so produced generate and maintain the sound.

When stationary waves are produced in a medium, certain equidistant parts of it are thrown into vibration having greatest amplitude. These places are called anti-nodes. There are other equidistant points placed exactly midway between any two anti-nodes where there is no vibration. These points are called nodes. The distance between any two consecutive nodes or antinodes is half the wave length of the waves producing stationary vibrations. Any periodic vibration in air is longitudinal in character. A stationary longitudinal vibration consists of regions of greatest and least variation of pressure at nodes and antinodes respectively. The existence of such regions can be experimentally demonstrated by a manometric flame (vide Basu & Chatterjee, Intermediate Physics, Sound, Chapter IX).

When stationary transverse waves are produced in a string stretched between two points, it is divided into a number of vibrating segments or loops which are actually seen. Nodes and antinodes are always found to be equidistant from each other. If the distance between *any two consecutive* nodes or antinodes be d cm., then the wave length of any component wave of the stationary wave-system is $2d$ cm. Further if the frequency of vibration of the stationary wave is n cycles per sec., then since wave velocity is the product of the wave length and frequency, the velocity V of any component waves forming the stationary wave system is given by $V = 2\,dn$ cm. per sec. If the wave length is expressed in feet, then wave velocity is given in ft. per sec.

Pipe Open at both Ends

When a source of sound vibrates in front of an open pipe so as to produce a series of compressions and rarefactions within it, stationary waves are produced. Antinodes are always formed at the open ends. The simplest possible mode of vibration is that when there is only one node at the middle of the tube and two antinodes at the ends. If l be the length of the pipe, it can be shown that the frequency n of sound emitted by the pipe is $V/2l$

where V is the velocity of the wave. This frequency is called the fundamental tone of open pipe. In fact when a pipe is blown strongly a mixed tone is produced, which consists of the fundamental n and a few other tones of higher frequencies. In the case of a pipe open at both ends the higher tones have got the frequencies $2n$, $3n$, $4n$. etc. n being the frequency of the fundamental tone.

Pipe Closed at one End

When air column vibrates in resonance within a pipe closed at one end, the open and the closed ends are always seats of antinode and node respectively. The simplest case of vibration is that the pipe containing only one antinode and one node. If l is the length of the pipe it is evident that this is the distance between a node and the next antinode. Therefore $l=\frac{\lambda}{4}$ where λ = wave-length of the constituent wave,

$$\therefore \quad n=\frac{V}{4l}$$

Since $V=n\lambda$ and $\lambda=4l$

The note having such a frequency is called the fundamental tone. When strongly blown the higher tones of such a closed pipe are $3n$, $5n$, $7n$, etc.

Open End Correction

Rayleigh showed that the seat of an antinode in a stationary vibration of a pipe is not *exactly* at its open end but it is always a bit outside the open end. The wider is the pipe, the more displaced is the antinode from the open end. This is due to the sound waves spreading out from the mouth of the pipe and is due to a phenomenon known as diffraction of sound waves. According to Rayleigh, the distance between the actual position of the antinode and the closed end for fundamental tone is $l+{\cdot}3d=\lambda/4$.

Date— EXPERIMENT 110

To Determine the Velocity of Sound by Resonance Air Column Method

Theory—If l be the depth of the water level within a pipe at which first resonance occurs with a source of known frequency n and if d be the diameter of the resonance pipe, then

$\lambda=4\ (l+{\cdot}3d)$ whence $V=4n\ (l+{\cdot}3d)$

Apparatus—A resonance air column and a tuning fork.

A resonance air column consists of a tall glass jar almost filled with water (Fig. 211). A glass pipe can be clamped vertically over the jar at any position so that the length of exposed column can be altered.

Procedure—Keep the glass pipe almost vertically submerged in water and strike tuning fork of known frequency against a pad and hold it just above the glass tube. Now slowly raise the glass tube vertically and when the sound of the tuning fork dies away, strike it again and hold it similarly. You would get a position of the tube when a magnified sound of tuning fork is heard. Now accurately adjust the height of the tube when you hear the loudest sound. Clamp the pipe there and measure with a metre scale the length of the air column from the water level L to the top of glass tube E. Raise the tube a bit higher and slowly and slowly as you lower it, find again the resonance length in a similar way. The mean of these two readings would give the required length. Take a number of such readings and find the mean value. With a callipers measure the internal diameter of the pipe at 2 or 3 positions and find the mean diameter.

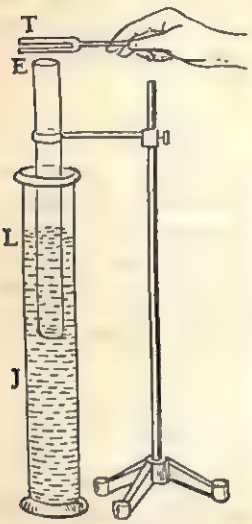


Fig. 211

Results—Frequency of the tuning fork = 384 per sec.

Diameter of the tube = (i) 3·8 (ii) 3·8 (iii) 3·8 cm.

∴ Mean Diameter = 3·80 cm.

Temperature of the Laboratory = 30°C

Observations	Length of the air column		Mean length	Wave length $\lambda = 4 \times (1 + 0{\cdot}6d)$	Velocity $= n\lambda$
	Tube raised	Tube lowered			
	cm.	cm.	cm.	cm.	metres per sec.
1.	21·6	22·0			
2.	...	...	21·8	91·7	350
3.	...	...			

Discussions—The measured velocity corresponds to the temperature of air within the tube, which is 30°C. Also air within the tube is nearly saturated with water vapour. These two corrections can be made and velocity of sound in dry air and at 0°C can be calculated out.

Temperature Correction—If V_t and V_0 denote the velocities of sound at t°C and 0°C respectively, then it can be shown that

$$V_t = V_0(1 + {\cdot}00183t)$$

Hence knowing V_t and t, V_0 may be determined. From the preceding experiment $V_t = 350$ metres/sec. and $t = 30$°C.

$$\therefore \quad 350 = V_0(1 + {\cdot}00183 \times 30)$$

whence $V_0 = 332$ metres per second.

Elimination of End effect—In equation $\lambda = 4(l + \cdot 3d)$, the factor $\cdot 3d$ is called the end correction. At the mouth of the pipe the form of the sound wave undergoes a modification and consequently this correction is necessary. But since this factor depends upon the relative condition of air and the diameter of the pipe, it is rather uncertain and it should better be eliminated.

If the end correction be c and if the first resonance occurs at a length l_1 of the pipe, then

$$\frac{\lambda}{4} = l_1 + c$$

Then the tube is raised still higher to get the position of resonance. If this length of the pipe be l_2 then

$$\frac{3\lambda}{4} = l_2 + c$$

From the two equations $\frac{\lambda}{2} = l_2 - l_1$

whence $\lambda = 2(l_2 - l_1)$

Hence $V = 2n(l_2 - l_1)$ ... (1)

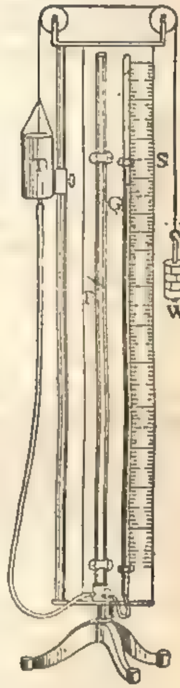


Fig. 212

Modified Apparatus—A long resonance column with a mechanical water level adjuster is necessary to eliminate the end effect. The apparatus consists of a glass or a metal pipe P about 5 ft. in length rigidly fixed to a vertical stand (Fig. 212). An water reservoir T slides over a rod or a groove and it may be fixed at any height of the stand. A rubber tubing is connected to the water reservoir and lower end of the pipe. If the reservoir is raised, the water in seeking its own level, would rise within the pipe. By this arrangement, the length of the air column within the pipe can be adjusted to any value. In case of metal pipe, serving as the resonance column, a narrower glass pipe G connected to the base, is attached parallel to the metal pipe to facilitate observation of the water head. A metre scale S is fixed along side the resonance column to read the length of the air column directly.

To start the experiment, the reservoir is raised to the topmost position. The tuning fork of frequency n is struck and held at the mouth of the pipe. Then the reservoir is slowly lowered. At some position, the resonance is heard. The experiment is done with due care and the water level is read as accurately as possible at the first resonance point. This reading is taken a number of times by increasing or decreasing the length of air column. Let the mean length of the air column be l_1 cm. The water reservoir is then further lowered till a second resonance point is obtained and here also a number of readings is taken. Let the mean length of the air

column be l_2 cm. Then knowing l_2, l_1 and n, the velocity of sound V, at the temperature of the room and at the saturated vapour pressure corresponding to the temperature, is found. The velocity of sound may be reduced at N.T.P.

ORAL QUESTIONS

How is the vibration of air column started and maintained within the tube? Distinguish between a node and an antinode. What is the difference between a longitudinal and a transverse wave? What type of wave is a sound wave in air? Give the points of difference between progressive wave and stationary wave.

Vibration of Strings

A piece of string or wire stretched between two fixed points is capable of either longitudinal or transverse vibrations. In either of the cases stationary waves are generated in the wire due to reflection of the wave system from the fixed ends. When the wire is rubbed along its length with a piece of chamois leather or wet cloth, longitudinal waves are produced in it and the wire emits a shrill sound. If, on the other hand, it is plucked, struck or bowed at any point the wire presents a blurred appearance. In this case the vibration of the wire is transverse in nature and it produces the characteristic sound.

It can be shown from theoretical considerations that if T is the tension of the string, m the mass per unit length of the string and λ is the wave length of the waves generated in it, then the fundamental frequency n of the transverse vibration is given by the relation.

$$n=\frac{1}{\lambda}\sqrt{\frac{T}{m}}$$

A piece of wire can be made to vibrate transversely into a number of loops or segments. Most generally it is made to vibrate in one segment, in which case the two fixed ends of the wire are positions of nodes and the middle point forms antinode. In this case the length of the wire between two fixed points is equal to half the wave length. If l is this length, then $l=\lambda/2$ and hence the expression stated above simplifies to,

$$n=\frac{1}{2l}\sqrt{\frac{T}{m}}$$

In fact the note emitted by a string is not of a single frequency as given by the expression, but it consists of a number of frequencies which are all multiples of n, called *harmonics*. The lowest frequency of the series of tones is n, which is called the *fundamental* Harmonics are much fainter than the fundamental. The note that we hear from a vibrating string is due to the blending of the fundamental and higher harmonics. Sounds of the same pitch are distinguished from each other due to the presence and intensity of harmonics in different proportions.

Determination of Pitch of a Sound

The pitch of a musical note is a measure of its acuteness. It may be verified from sources of sound of variable frequency. The higher is the frequency, the more acute is the sound. From this we conclude that pitch of a sound depends upon its frequency. (Vide Basu & Chatterjee's Intermediate Physics, Sound. Chapter VII).

From what is stated above, it follows that two sources emitting sounds of the same pitch have got the same fundamental frequency. This is one of the methods of determining frequency of a source. A source B of constant frequency is made to produce a sound and another source C whose frequency can be varied, is sounded before it. By trial the frequency of C is so made that the two sounds appear to be of the same pitch. If now the frequency of C can be found, the frequency of B is known.

The source of variable frequency is generally a piece of wire stretched between two points. By altering the length of vibrating segment or by changing the tension of the wire, the note emitted by the string can be tuned with the sound of a source. The frequency of the wire can be found by knowing its vibrating length, tension and mass per unit length of the wire.

Date— EXPERIMENT 111

To Determine the Frequency of a Tuning Fork with a Sonometer

Theory—If a tuning fork be in resonance with a length l of the sonometer wire, having a tension T and of a mass per unit length m; then frequency n of the fork is given by the formula.—

$$n=\frac{1}{2l}\sqrt{\frac{T}{m}}$$

Apparatus—A sonometer, tuning fork, a sample wire, balance and a weight box.

A sonometer consists of a rectangular hollow wooden board S provided with a metre scale at the top (Fig. 213). One or two

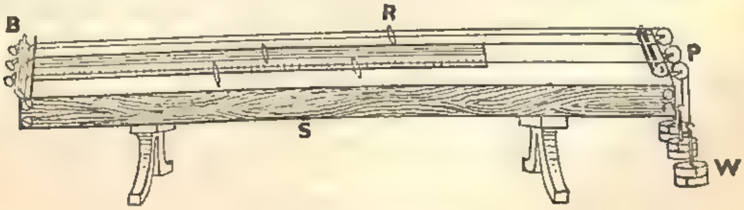


Fig. 213—Sonometer

metal wires have their one ends fixed to one or more pegs B while the other ends pass over pulleys P and are stretched by adjustable loads W. The slotted loads can be put upon a suitable pan and

thereby the amount of stretching can be adjusted. In some apparatus there are two pieces of wires, one of which is stretched by adjustable loads and the other is stretched parallel to this wire and is fixed between two pegs. The fixed wire is called the comparison wire and is used to verify the laws of transverse vibration of strings. There is a number of thin vertical wooden strips, called bridges, over which the wire is stretched. These bridges can be shifted anywhere on the board and thus the length of the vibrating segment of the wire can be altered. The function of the hollow board is to increase the loudness of the tone emitted by the wire or any other vibrating source placed in contact with the board.

Procedure—Suspend the weight-hanger *of a known mass* at the end of the experimental wire of the sonometer and place a load of 1 or 0·5 kilogramme on the weight-hanger so as to stretch the wire. Place two adjustable bridges on the board just under the wire. Hold the tuning fork, under examination, by its *stem* and after striking it *softly* against a suitable pad, place it with the stem touching the board. A magnified sound of the tuning fork is heard due to the forced vibration of the hollow wooden board of the sonometer. Now pluck with a finger the wire between the two bridges to produce a sound. Now carefully listen to the two notes which would generally appear to be different. Alter the position of any one bridge and pluck the wire so as to produce its note; at the same time strike the tuning fork and place it on the board. In this way by repeated trials make the two sounds appear identical. Those, who have musical ears, can do this easily but others may require some preliminary practice before they can acquire an experience of tuning. When the two notes sounded together produce a throbbing effect, it is known as beats. Then the two sounds are very nearly alike in pitch. Now adjust the length of the wire such that on plucking it and at the same time by striking the tuning fork, the beats disappear completely. At this stage a small piece of paper placed on the sonometer wire jumps as soon as the struck tuning fork is placed on the board. This is called the resonance between the fork and the wire. At resonance the frequencies are equal.

Now measure the length of the wire between two bridges either directly with the scale provided or with a separate metre scale. Slightly displace any bridge and again re-adjust its position, in a manner already stated to get resonance. In this way take at least five such readings of the length of the string for the same load and get the mean value. Convert the total load on the wire in *grammes* and multiply the number by the acceleration due to gravity g in C.G.S. units. The product is the value of the tension T in absolute units. To find the mass per unit length m of the wire, a sample wire having the same diameter and material is supplied. Measure its length with a metre scale two or three times and get the mean value of the length of the sample wire. Then find its mass with a sensitive balance. The mass in grammes divided by its length gives m. Then from the formula find the frequency n.

Results—

(Details of determination of mass per unit length to be given.)

No. of Readings	Position of first bridge	Position of second bridge	Length of vibrating wire	Tension of wire	Mass of unit length of wire	Observed frequency	Mean frequency
	cm.	cm.	cm.	dynes	gm.	per sec.	per sec
1	20·0	44·1	24·1	3000×980	342	342	
2	...	...	24	...	...	340	
3	30·2	56·1	25·9	3500×980	...	343	343
4	...	...	...	...	...	...	
5	42·6	...	26·0	...	...	341	

Discussions—The tuning fork should be made to touch the board softly while the paper rider is on the wire, otherwise the paper would fall down due to the jerk of mechanical impact. The gradual adjustment of the length of the sonometer string by eliminating the beat frequency at the resonance point is an accurate method and should be practised very often. The mass per unit length of the wire should be very accurately measured, since a small error in measuring this quantity introduces a large error in the determination of frequency.

ORAL QUESTIONS

What is the nature of vibration of a stretched string? Distinguish between transverse and longitudinal waves. Can you produce longitudinal vibration in a string? What should be the nature of pitch in such a case? State the laws of transverse vibration in a stretched string. What is the principle of tuning a certain length of a string with a tuning fork? Why does a rider fly off when a tuning fork is placed near a reasonant auxiliary wire? What is the effect of frequency on a violin string when (*i*) a wire is gradually tightened, (*ii*) a thicker wire is used in the place, (*iii*) when the bowed segment is gradually shortened?

Laws of Transverse Vibration of Strings

The fundamental tone of frequency n produced by the string is given by the expression,

$$n=\frac{1}{2l}\sqrt{\frac{T}{m}}$$

where l = length of the vibrating segment, T = tension of the string and m = mass per unit length of the string.

Since the factors l, T and m are all experimentally variable, n will vary as each of them is altered in value. Hence we can state laws of transverse vibration of string in the following way,—

(*i*) **Law of Length**— $n \propto 1/l$ when T and m are constants; that is *the frequency of transverse vibration of a stretched string is inversely proportional to its vibrating length* for the same or a similar string (for m to remain constant) under a constant stretching force.

(*ii*) **Law of Tension**—$n \propto \sqrt{T}$ when l and m are constants; that is, *the frequency of transverse vibration of a stretched string is inversely proportional to the square root of its tension* for a given length of the same or similar string.

(*iii*) **Law of Mass**—$n \propto 1/\sqrt{m}$ when l and T are constants; that is, the frequency of transverse vibration of a stretched string varies inversely as the square root of its mass per unit length for a given length and tension of the string.

Date—

EXPERIMENT 112

To verify the Law of Length in Transverse Vibration of a Stretched String

Theory—The first law states that the frequency of transverse vibration of a stretched string varies inversely as the length of the vibrating segment for the same or a similar string under a given tension.

That is $n \propto \dfrac{1}{l}$ when T and m are constants

or $n \times l =$ constant.

Apparatus—A sonometer, a weight hanger and some weights, a metre scale, a number of tuning forks.

[A description of a sonometer as well as its figure may be given here.]

Procedure—Stretch a suitable metal wire over the sonometer board and suspend a weight hanger at its end. Put a load of 1 to 2 kgm. on the hanger so as to stretch it. Mount two movable bridges on the board below the wire.

Out of the set of tuning forks supplied, take the one having the highest frequency. Strike it on a soft pad and place it on the sonometer board. A note is emitted. Pluck the string in between the two bridges and compare the notes emitted by the string and the tuning fork. Now strike the fork from time to time and alter the length of the wire by moving any one bridge and at the same time pluck the wire. By repeated trials make the two sounds of equal pitch. When the note emitted by the string appears to be of the same pitch as that of the tuning fork, measure the length of the string between the bridges. Repeat the observations thrice.

The test the equality of pitch place a small paper rider on the wire at the central part between the bridges. This should be done when the sounds of the tuning fork and wire appear nearly equal. Now striking the tuning fork place it on the board and *very* slowly adjust the position of any one bridge. By repeated trials, a position is secured when the rider is thrown away just the moment the struck tuning fork is placed on the sonometer board. This is the visual method.

The audition method is as follows ; Strike the tuning fork and place it on the board, and at the same time pluck the string. Beats may heard when the sounds are nearly the same. Adjust the length of the wire and by repeated trials get the point when beats due to the tuning fork and string vanish. If the length be found to be too short, the wire may be further stretched by additional loads to secure satisfactory length of resonance.

In a similar way get the resonant lengths of the string corresponding to all the tuning forks and tabulate the results. The product of frequency and the corresponding length is shown to be constant which proves the first law.

Results—The tension of the wire =

No. of readings	Frequency of tuning fork	Length of vibrating segment				Frequency × length
		First reading	Second reading	Third reading	Mean	
1						
2						
3						
4						
5						

Discussions—The product of frequency and length is a constant for a particular tension and a sample of wire. If the tension of the sonometer wire is changed, the value of the constant changes.

Date— EXPERIMENT 113

To Verify the law of Tension in Transverse Vibration of Strings.

Theory—The law of tension states that the frequency of transverse vibration of a stretched string varies directly as the square root of tension provided that the length of the vibrating segment and mass per unit length of the string do not change.

That is, $n \propto \sqrt{T}$ if l and m are constants.

Apparatus—A sonometer, weight hanger, a set of loads, weight box, a few tuning forks.

Procedure—Out of the set of tuning forks supplied, take the one having the maximum frequency. Calculate the highest permissible load from a knowledge of the material and cross-section of the sonometer wire (vide Experiment on Young's modulus), and put this load (including the weight of the weight hanger) to stretch the string. Then strike the tuning fork and place it on the sonometer board. Adjust the position of the bridges on the board to produce resonance. Note the frequency of the tuning fork and the load at the end of the wire.

Next take another tuning fork of just lower frequency and tune it with the sonomoter wire by altering the load keeping the distance between the bridges same. Take two observations for the

load for the same tuning fork, when the load is gradally decreased from a higher value and when it is increased from a lower value. The mean of these readings gives the true load for that frequency.

In this way, find the tensions corresponding the frequencies of all the forks supplied and tabulate the results. Finally, show that the ratio of $n/\sqrt{T}$ is constant, T in each case being reduced to absolute units.

Results –

No. of readings	Frequency of Fork	Load on String			Tension = load × g	Ratio $n/\sqrt{T}$
		load decreasing	load increasing	Mean load		
		gm.	gm.	gm.	dynes	
1	...	...	...	...	...	.
2	...	...	...	...	...	...
3	...	...	...	...	...	...
4	...	...	...	...	...	...
5	...	...	...	...	...	...

Discussions—For higher loads on the string, the resonance point appears to be less sensitive with a small variation of load. Tuning under this condition is to be made better by beats method than by the paper rider. To show the constancy of the ratio the tension of the string must be expressed in absolute units. Although by higher loads the length of the wire increases very slightly, the mass per unit length of the wire remains fairly uniform.

Auxiliary Wire Method

When loads of all possible values are not are available, the verification may be made indirectly with an auxiliary wire stretched between two pegs under constant tension on the sonometer board.

A tuning fork of a known frequency is taken and the experimental wire is stretched with a known load having tension T. Also the auxiliary wire is put under a constant tension. The tuning fork of frequency n is tuned with the experimental wire as also with the auxiliary wire. Let the length of the vibrating segment of the auxiliary wire be l

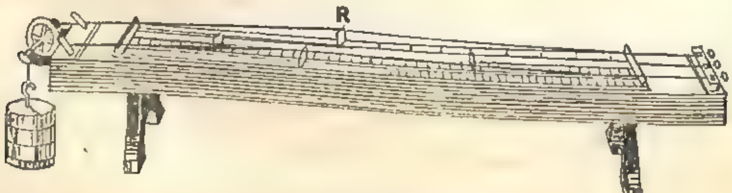


Fig. 214—Sonometer

Now the tension of the experimental wire is changed to a value T_1 without the changing the length between its bridges. It is now

plucked at any point between the bridges and tuned with the auxiliary wire by altering the length of the vibrating segment. Let its length be l.

Since the tension of the auxiliary wire is constant, the frequency of the string for a vibrating segment of length l would be by first law nl/l_1 which is say, n_1. Since frequency is resonant with the experimental wire under tension T_1, then for second law to hold $n/\sqrt{T} = n_1/\sqrt{T_1}$. A number of readings for n for various values of T is taken and the results are tabulated in the following way.—

No. of readings	Tension of expt. wire	Fundamental length l of auxiliary wire	Altered length l_1 of auxiliary wire	Calculated frequency nl/l_1	Ratio $n/\sqrt{T}$
	dynes	cm.	cm.		
1 2 3 4 5					

The method has a better advantage over the previous one in as much as the auxiliary wire works as a source of variable frequency and hence changing the tension of the experimental wire by fixed loads is practicable for the verification of the law of tension.

Oral Questions

What sort of vibration is executed by the sonometer wire? What are the characteristics of a stationary vibration? What is the effect on sound produced if you decrease the length of the wire or decrease the tension of the wire? Why is the sonometer board made hollow? What are the functions of the bridges on the board? What is the effect on sound if you use a thicker wire of the same material and under equal tension?

Date—

Experiment 114

To Verify the Law of Mass in Transverse Vibration of Strings

Theory—The law of mass states that the frequency of transverse vibration of a string varies inversely as the square root of mass per unit length of the string provided that the length of the vibrating segment and tension of the string remain constant.

That is, $n \propto \dfrac{1}{\sqrt{m}}$ if l and T are constants or $n\sqrt{m}$ is a constant.

Apparatus—A sonometer, one tuning fork and a few loads, and samples of wire.

Procedure—Fit an auxiliary wire on the sonometer board under some reasonable tension between two pegs. Take a sample wire of the same specification, and measure its length, say L cm. Find its mass M in a balance. Hence mass per unit length of the wire is found.

Then stretch the sample wire by some load and put two wooden bridges under the wire. With a tuning fork of known frequency n, adjust the length of the wire resonant with it. Make also a known length of the auxiliary wire resonant with tuning fork. Let the length of the tuned part of the auxiliary wire be l. Then find product of $n\sqrt{m}$.

Next take another sample wire and find its mass m_1 per unit length in a similar way. Place it on the board under the *same tension* having an *equal length* between the bridges. Tune the note emitted by the string by adjusting the bridges of the auxiliary wire. If l_1 is the length of the vibrating segment of the auxiliary wire, then its frequency is nl/l_1, which is, n_1 being the frequency of the experimental wire. Find the product of $n_1\sqrt{m_1}$.

In this way a number of observations is repeated with different samples of wire under constant tension and length. The frequency and the mass per unit length in each case are determined and the results are tabulated,

Results—

No. of reading	Total Length of expt. wire	Mass of wire	Mass per unit length	Fundamental length of aux. wire	Altered length of aux. wire	Calculated frequency nl/l_1	Product $n\times\sqrt{m}$
	cm.	gm.	gm./cm	cm.	cm.	per. sec.	
1							
2							
3							
4							
5							

Discussions—Direct verification of the law of mass is not possible without the auxiliary wire, since we cannot obtain samples of wire or tuning forks of a continuously variable mass or frequency. The accuracy of the method lies in measuring the mass per unit length of the wire and the frequency in any particular set of observation. Hence the frequency is to be determined by the method of beats.

Date—

EXPERIMENT 115

To draw graphically the relation between Frequency and Length of a stretched string under given tension and hence to find the frequency ot Tuning fork

Theory—The frequency of transverse vibration n of a stretched string under a constant tension varies inversely as the length l of the vibrating segment. Thus $n\times l=$constant. The graph is a rectangular hyperbola.

Apparatus—A set of 5 or 6 tuning forks of known frequencies, one tuning fork of unknown frequency, a sonometer, a weight hanger, some loads and a metre scale.

Procedure—Attach the weight hanger of *known mass* to the sonometer string and put a load of 1 to 2 kgm. on it. Take the tuning fork of highest frequency and roughly determine the length of the string for which it may be tuned with the tuning fork according to the directions given in Expt. 111. If the length appears to be less than 14 or 15 cm., increase the load on the weight hanger until this length becomes 20 to 30 cm. Ofcourse you must guard that the load does not stretch the wire beyond the limit of elasticity (vide Expt. on Young's modulus).

When proper load has been put, take the tuning fork of the lowest frequency and tune it by adjusting the length to the sonometer wire, either by eliminating beats or by using a paper rider (vide Expt. 111). Measure the length of the wire by a metre scale. Take three such observations for this tuning fork and get the mean length of the wire.

Then take the tuning fork of next higher frequency and in a similar way find the mean resonant length of the string for three observations, the load on the string remaining the same. In this way find the mean length corresponding to all the tuning forks of known frequencies. Lastly find the mean resonant length, under the same tension, of the tuning fork of unknown frequency.

Results—Similar to Expt. 111. Choose suitable units on a graph paper with frequency as abscissa and length of the vibrating segment as ordinate, and plot various values of n and l as found from the experiment. Find the mean length of the wire corresponding to the unknown frequency of fork supplied. Refer to the graph and thence find out the frequency.

Discussions—The same as Expt. 111.

CHAPTER VII

EXPERIMENTS ON MAGNETISM

Magnets

A magnet is metallic substance, having two distinctive properties : (*i*) when dipped into iron filings, it picks up some quantity of filings at its two ends : (*ii*) when suspended with a string so as to swing freely, it comes to rest with the same two ends pointing north and south.

The most common types of artificial magnets used in the laboratory are *bar magnets, horse-shoe magnets and magnetic needles.* Each magnet has got two poles ; the one pointing north is called the north pole and the other pointing south is the scuth pole. The pole is supposed to be one/point situated within the body of the magnet near each end from which the resultant force of attraction or repulsion acts at end. The imaginary line passing through the two poles of a magnet is called the *magnetic axis.* The distance between two poles measured a long the axis is called the equivalent length of a magnet. The vertical plane passing through the axis of a freely suspended magnet is called the magnetic meridian.

Laws of Magnetic Attraction and Repulsion

On presenting north pole of a magnet near the north pole of another suspended magnet, it is found that there is repulsion between the poles. The same thing happens when two south poles are brought near each other. If however, a north pole is brought near the south pole or a south near the north an attraction is observed. From this it is concluded that *like poles repel and unlike poles attract* each other.

From the fact that all freely suspended magnets come to rest with their north poles pointing the northerly direction of the earth, it is assumed that the earth behaves as a huge magnet with its south pole somewhere near the north geographical pole and north magnetic pole near the south geographical pole. It is due to the mutual action between the suspended magnet and the earth's magnetic field that all freely suspended magnets point north and south.

Methods of Magnetisation

The act of infusing the properties of a magnet into a magnetic substance is known as *magnetisation.* There are broadly two methods by which artificial magnets may be prepared—(*i*) by rubbing and (*ii*) by electrical or magnetic induction method The method of rubbing is again subdivided into *three* parts,—(*i*) method of single touch. (*ii*) divided or separated touch and (*iii*) double touch. For details of these methods students are referred to Basu & Chatterjee's Intermediate Physics.

Precautions to use a Magnet

Students are particularly warned against roughly handling a magnet which considerably weakens the strength of the magnet and may completely demagnetise it ; *e.g.*, heating a magnet in a burner, using the magnet as a hammer, violent jerking of the magnet such as dropping it on the floor, placing two like poles of the magnets very near each other etc.

A bar magnet left to itself is subject to a de-magnetising force which slowly weakens the pole-strength. Hence after finishing work with bar magnets, they are to be kept in pairs with opposite poles facing the same direction and with two pieces of iron in contact with the ends. Such an arrangement is known as magnetic keepers.

Date— EXPERIMENT 116

To Determine the Magnetic Meridian at a Place

Theory—The vertical plane passing through the axis of a freely suspended magnet is called the magnetic meridian.

(Compass needle method)

Apparatus—A compass needle, drawing board and paper, two hair pins and some thread.

Procedure—Fix a piece of drawing paper on a rectangular board. Place a compass needle at the central portion of the board. The needle should be about 5 or 6 cm. long and mounted on a vertical pivot. Take two hair pins and fix them vertically on the board. Tie a piece of thread on the hair pins a little above the compass needle. Now rotate the board in such a way that on looking vertically the thread and the needle are in one line. Then the vertical plane passing through the thread is the magnetic meridian. The pins are then removed and their feet are joined by a straight pencil mark which gives the section of the meridian by the plane of the paper.

Results—The line drawn on the drawing paper is the result obtained.

Discussions—The piece of thread is stretched paralled to a magnetic needle with an eye estimation and hence the method is approximate. Morveover the magnetic pole of the needle may not exactly coincide with the pointed ends of the needle.

If there is any magnetic meterial near by, *e.g.*, pieces of iron such as iron pipes, joists, window bar etc., the position of rest of the suspended needle may be affected and hence the apparent position of the magnetic meridian may alter considerably.

(Bar magnet method)

Apparatus—A bar magnet, unspun silk thread, vertical stand, drawing board, paper and a few fixing pins.

Procedure—Fix a sheet of drawing paper on a rectangular board. Suspend the bar magnet horizontally on a suitable rider

from the vertical stand by means of unspun silk thread and place the stand on the paper. The suspended magnet should be close to the level of the paper. Take two short pieces of straight copper wires and fix them vertically at two diametrically opposite corners of the bar magnet with paraffin wax or glue. Each wire should project equally at the top and bottom of the magnet.

When the freely suspended magnet becomes stationary, mark two dots with a fine pencil on the paper just under the points of the wires. Turn the magnet upside down without disturbing the position of the stand. When the magnet becomes stationary again, mark two pencil dots just under the points of the wires. Join the two pairs of points by two straight lines. These straight lines would make an angle along the length of the magnet. Bisect the angle by geometrical method. The bisector of this angle is the axis of the suspended magnet. The vertical plane passing through the bisector gives the magnetic meridian.

Result—The line drawn on the paper is the result obtained.

Discussions—There should not be any torsion of the suspension thread as otherwise the axis of the magnet will not be parallel to the magnetic meridian.

Oral Questions

What is called the pole of a magnet? Define magnetic meridian. Is magnetic meridian a fixed plane on earth's surface? Why is it that a freely suspended magnet always points north and south? What is declination? Is it always and at all places a fixed quantity? In finding magnetic meridian, why is a needle preferable to a bar magnet?

Magnetic Lines of Force

If an isolated north pole be imagined to be placed at any point near a magnet, it will be influenced by both the poles of the magnet; north pole repelling it and south pole attracting it. Consequently under the mutual action of two poles this isolated north pole would move along a certain curved path from the north to the south pole. Such a curve which represents the path of motion of a single north pole in a magnetic field is called a line of force. A line of force may also be defined to be a continuous curve in a magnetic field such that the tangent at any point of it represents the direction of the resultant intensity at the point.

An isolated pole is not practically available. If we place a pivoted magnetic needle in a field, the north pole of the needle will be urged in the direction of the line of force and its south pole in the reverse direction. Consequently, the needle tilts and takes up such a position that its magnetic axis becomes a tangent to the line of force passing through the axis of rotation. If the needle is sufficiently short we may say that the needle lies along the line of forces passing through its centre.

Date—

EXPERIMENT 117

To Trace the Lines of force due to a Bar Magnet and to find Neutral Points

Theory—A line of force in magnetic field is a curve such that the tangent at any point to it represents the resultant field at that point. The axis of a very short and freely suspended compass needle, placed anywhere in a magnetic field, gives the position of a line of force at that region.

A neutral point in a magnetic field is that point where the resultant magnetic field is zero. Hence a sufficiently short magnetic needle placed at this point will not be influenced by the field and may take up any position of rest.

Apparatus—A drawing board, paper fixing pins, some thread, a bar magnet and a short compass needle.

Procedure—Remove magnet and magnetic substance from the table. (Fix a sheet of drawing paper on a board and place the bar magnet at the middle of the board and draw its outline with a fine pencil.) Next remove the bar magnet to a distance and place the compass needle upon the outline of the magnet. Slowly rotate the board until the longer edge of the outline is parallel to the axis of the needle. Fix the board there by fixing pins. Place the bar magnet upon the board on its outline according to the direction given (either north pole pointing north or south pole pointing north). The bar magnet has now been placed in the magnetic meridian. Now place the compass needle in contact with the north pole of the magnet. After the needle has become stationary, give two pencil dots marking the two ends of the needle. Then shift the needle to a position such that the pencil dot which was formerly given against the north pole is now in contact with the south pole of the needle. Give another pencil dot at the north pole of the needle. Again shift the compass needle so that the last dot is now in contact with the south pole. In this way gradually shift the compass needle and plot points until the needle comes to the south pole of the bar magnet. The gradual change of inclination of the compass needle as it is brought from the north to the south pole is shown in Fig. 215. Draw a continuous free hand curve through all the points thus plotted. This curve gives a complete line of force due to the bar magnet.

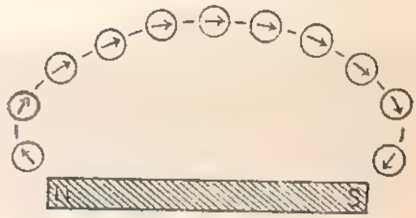


Fig 215

Bring back the magnetic needle to the north pole of the bar magnet to a slightly different position and in a similar way trace out another line of force. In this manner by successively starting from the various points of the north pole of the bar magnet, trace

out the whole field surrounding the bar magnet. Since the distribution of lines of force is symmetrical with respect to the axis of the bar magnet it is sufficient to draw one half of the field (shown by continuous lines in Fig. 216 and 217). The other half may be

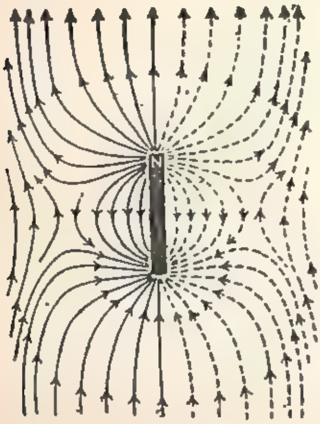


Fig. 216

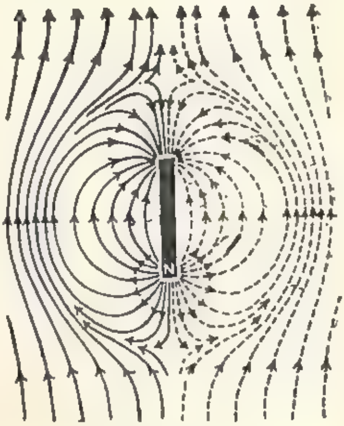


Fig. 217

completed by free hand drawing or may be left blank. Fig 216 shows the lines of force due to a bar magnet with its N-pole pointing north, Fig. 217 shows the distribution lines of force when N-pole points south. In both the figures a few other lines of force are found which are completely separated from the magnet. These are the lines of force due to the magnetic field of the earth. To trace them the magnetic needle has got to be placed at a fair distance from the magnet and the lines of force due to earth near the vicinity of the magnet may then be drawn.

On drawing extensive lines of force, two equidistant points are found which are bounded on all sides by lines of force. At these regions the needle has got no specific direction of rest. These are called neutral points.

Results—The figure drawn gives the results.

Discussions—The magnetic needle point should be placed accurately on the dots previously given. The neutral points in each figure would be found equidistant from the centre of the magnet. At the neutral points the horizontal field of the earth is equal to the field due to the magnet.

Oral Questions

Define magnetic lines of force. What is the idea behind the drawing of lines of force by a magnetic needle? Is the distribution of lines of force identical for any position of a bar magnet? If not, why? Is any magnet influenced by electrostatic lines of force? What are the properties attributed to the lines of force? Define neutral point. Is it possible to have an idea of the pole strength of a bar magnet by examining the position of the neutral point in its field; if so how?

Date— EXPERIMENT 118

To Determine the Poles of a Bar magnet and hence to find the Ratio of the Magnetic length to the actual length of Bar magnet

Theory—The pole of a bar magnet is a point within it at which the resultant of all the forces at that end acts.

Apparatus—Drawing board and paper, fixing pins, a bar magnet, a compass needle, two long pins, some thread.

Procedure—Fix the paper upon the board and place the compass needle upon it, the bar magnet being far removed from it. Fix a fairly long piece of thread to two pins and fix the pins upon experimental table outside the drawing table so that the direction of the thread is parallel to the axis of needle. The thread then lies permanently along the magnetic meridian independent of the position of the drawing table (Fig. 218). Place the bar magnet on the drawing paper and draw its outline. Now place the compass needle near one end of the magnet. You would observe that the axis of the magnetic needle makes an angle with the overhead thread. Rotate the drawing table in a suitable direction until the compass needle becomes parallel to the thread. When that is done, mark with fine pencil point two dots at the two ends of the compass needle. Change the position of the needle slightly, keeping it almost at an equal distance from the pole of the bar magnet. You would observe that the needle makes some angle with the thread. Rotate the drawing table until the axis of the needle is parallel to the thread. Mark again two dots at the ends of the needle. In a similar way place the needle at a third position and making it parallel to the thread, mark two dots at its ends. Remove the magnet and the compass needle and draw a straight line through each pair of points. All the lines are found to pass approximately through one point near the end of the magnet. This point is the pole. In a similar way find the other pole.

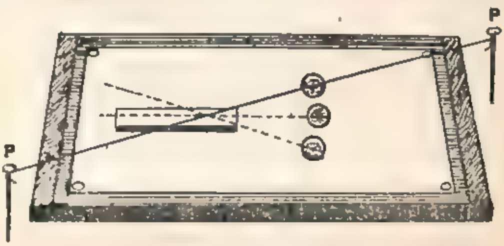


Fig 218

Measure the length of the bar magnet a few times with a slide callipers correct to the nearest milimetre. The mean value of such lengths represents the geometrical length of magnet. Measure the distance between the two poles as obtained with a divider and a metre scale or a diagonal scale. Hence get the ratio of the magnetic length to the actual length of the bar magnet.

Results—The diagram drawn is the result.

No. of readings	Distance between poles cm.	Length of bar magnet cm.	Ratio	Mean Ratio
1.	8·8	10·4	0·85	
2.	...	...	...	0·85
3.	...	...	...	

Discussions—The needle should be placed very near each end of the bar magnet in order that the lines may meet at a point otherwise the straight lines drawn through the pair of points will not pass through one point due to the curvature of lines of force. The magnetic meridian should be accurately found.

ORAL QUESTIONS

Define pole of a magnet. Why in determining the pole of a magnet the board is to be rotated every time to make the needle parallel to the magnetic meridian? Is it essential that the compass needle to be used should be short? What is the harm if it is long? Why is it that the equivalent length of a bar magnet is smaller than the geometric length? Can you explain the magnetism of a bar from the standpoint of the molecular theory?

Magnetic Intensity

It has already been stated on pp. 348 that similar poles repel and dissimilar poles attract each other. The space surrounding a magnet in which such forces exist is known as a *magnetic field*. The field strength at any point in a magnetic field is measured by the force exerted on a unit north pole placed at that point. The field strength is also known as the magnetic intensity and is measured in dynes per unit pole or in *oersted*. It has a direction and magnitude and hence it is a vector quantity. If H denotes the magnetic intensity at any point and a magnet pole of strength m is placed there, the force exerted on this pole is mH dynes.

Couple on a Magnet in a Uniform Field

Let a uniform field of intensity H be represented by the dotted arrow head (Fig 219) and a magnet NS of length $2l$ and of pole strength m be placed in this field at an angle θ with it. The north pole of the magnet would be urged in the direction of the field with a force mH and the south pole in the opposite direction with an equal amount of force. Hence a couple would act on the magnet tending to restore it parallel to the field.

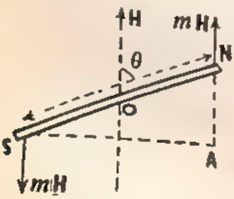


Fig. 219

Let AS be the perpendicular distance between the parallel forces, the moment of the restoring couple $= m\text{H} \times \text{AS}$.

But $\text{AS} = \text{SN} \sin\theta = 2l \sin\theta$ where θ = angle of deflection of the magnet.

$\therefore$ the moment of the couple $= 2ml\,\text{H} \sin\theta$.

Magnetic Moment—If the magnet is kept perpendicular to the field of unit intensity ($H=1$ oersted), the angle of deflection is 90°, and the moment of the couple reduces to $2ml \times \sin 90° = 2\,ml$. This value of the moment of the couple is called the moment of the magnet or simply *magnetic moment* and is usually designated by M. Hence the magnetic moment of a magnet may be defined as the moment of a mechanical couple which can keep the axis of the magnet at right angles to a field of unit intensity. Thus, $2ml = M$. The magnetic moment is also a vector.

Intensities at the End-on and the Broad side-on Positions. When the point in question lies somewhere along the axis of a bar magnet, it is called *end-on position* of the magnet. If the point is at a distance d from the centre of the magnet of length $2l$ at the end on position, the intensity at the point is given by $\dfrac{2Md}{(d^2-l^2)^2}$ oersteds where M is the magnetic moment.

Again when the point lies at any distance d from the centre of the magnet of length $2l$, along a direction perpendicular to its axis, it is called the *broad-side-on* position of the magnet. For this position the intensity is given by $\dfrac{M}{(d^2+l^2)^{\frac{3}{2}}}$ oersteds. (For details vide Basu & Chatterjee's Intermediate Physics. Magnetism, Chap. IV).

Tangent Law

Let there be two horizontal magnetic fields of uniform intensities F and H mutually perpendicular to each other. On placing a magnetic needle, which is free to rotate in a horizontal place, it would take up an equilibrium position at a certain angle θ with respect to H (Fig. 220). Let the needle be of equivalent length $2l$ and of pole strength m.

In the equilibrium position the moment of the couples due to the two fields acting on the magnet will be equal and opposite. The moment of couple due to $H = mH \times AS = mH \times 2l \sin\theta$. Again the moment of the couple due to $F = mF \times AN = mF \times 2l \times \cos\theta$,

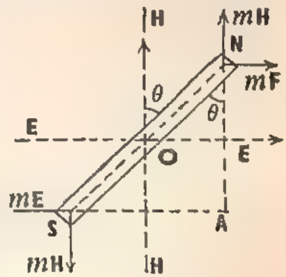


Fig. 220

$$\therefore\quad mH2l \sin\theta = mF2l \cos\theta \text{ whence } \frac{F}{H} = \tan\theta.$$

Thus when a magnet is placed in two mutually perpendicular fields the tangent of the angle of deflection of the magnet with respect to one field is the ratio of the intensity of the other to that field. This is called the Tangent Law.

Date—

EXPERIMENT 119

To Determine M/H using a Deflection Magnetometer from Tangent-A position

Theory—When the arms of a deflection magnetometer are placed along magnetic east and west and a bar magnet is so placed on any arm that the axis of the bar magnet, on being produced passes through the axis of rotation of the needle, it is known as the Tan-A position of Gauss. In this position,

$$\frac{M}{H}=\frac{(d^2-l^2)^2}{2d}\tan\theta$$

where $2l$ = equivalent length of the bar magnet,
d = distance from the axis of rotation of the needle to the centre of the bar magnet.
$M=2ml$ = magnetic moment of the bar magnet.
H = Horizontal intensity of the earth's magnetic field.
θ = deflection of the needle.

Apparatus—A deflection magnetometer and a bar magnet.

A deflection magnetometer consists of a very short magnetic needle either pivoted or suspended horizontally over the centre of a circular card board graduated in degrees (Fig. 221). The scale is graduated in each of the four quadrants from 0° to 90°. Two long and light pointers *pp* are fixed to the middle of the magnetic needle perpendicular to its axis. The ends of the pointers move over the circular scale so that any deflection of the needle may be read with any one of them. To protect the needle and the circular scale from the effects of wind and dust, they are enclosed in an wooden box with a glass cover. The box is provided with two long arms, A and B on opposite sides and a metre scale is fixed with each. The metre scales are graduated in such a way that zero of each begins from the centre of the needle. Each arm has got a long and straight groove through which a bar magnet may be slided. To

Fig. 221—Deflection Magnetometer

facilitate the readings of the pointers without parallax, some magnetometers are provided with a plane mirror fixed on the card board. When the pointer and its image in the plane mirror appear to be in one line, the line of sight is strictly vertical and there is no parallax error in taking reading. When the magnetometer box is

properly adjusted, the pointers record $0°—0°$ when the arms are either parallel or perpendicular to the magnetic meridian.

Procedure—Remove any magnet or magnetic material from the experimental table, otherwise the needle of the magnetometer might be disturbed due to its presence. Place the arms of the magnetometer east and west and then accurately adjust their position so that the pointers attached to the needle read $0°—0°$

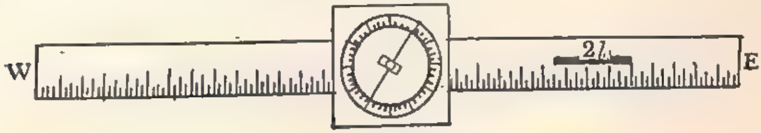


Fig. 222—Tan-A position with a magnetometer

or $90°—90°$ on the circular scale. (Fig. 222). It is here assumed that the magnetometer box is rightly placed with respect to its arms.

Measure the length of the bar magnet with a metre scale *three times* correct to the nearest millimetre or half-millimetre ; and find the mean geometric length. Let it be l'. The equivalent length of the bar magnet may be taken to be $0.9l' = 2l$. say.

Now place the bar magnet to the east of the needle alongside the scale with its north pole facing the needle. Make sure that the bar magnet has been so placed that the point on which the needle turns is along the axis of the bar magnet. The bar magnet is now placed *end on* with respect to the needle as shown in the figure. Now slide the magnet either near to or away from the needle to such a position that deflection of the needle is near about 45°. Note the position of the north end of the magnet with reference to the scale attached to the magnetometer. Let the reading be d'. To this add half the geometric length of the magnet to obtain d. Again half the magnetic length of the magnet is l.

For an equal distance of the bar magnet to the east of the needle take four readings of deflections *viz.*, (*i*) north pole facing the needle, (*ii*) north pole facing the needle but the magnet is turned upside down, (*iii*) south pole facing the needle, (*iv*) south pole facing the needle but the magnet is turned upside down.

Bring the magnet to the west of the needle at an equal distance and take a similar set of the four readings. The mean of all these deflections is taken to be the deflection of the needle at this distance.

Results—(Typical)

Mean geometric length of the bar magnet $= l' = 10.2$ cm.

$\therefore$ Equivalent length of the magnet $= .9l' = 2l = 9.2$ cm. or half the equivalent length $= l = 4.6$ cm.

No. of Readings	distance of nearer pole $=d'$	½ geometric length $=l'/2$	distance d $=d'+l'/2$	Position of Bar magnet	½ equivalent length $=l$	deflection θ	Mean deflection	$\frac{M}{H}$
	cm.	cm.	cm.	E of needle	cm.	deg.	deg.	C.G.S.
1	21·4	5·1	26·5	N facing needle	2·6	46		
2.	...	...	...	Upside down		...		
3.	...	...	...	S facing needle		...		
4.	...	...	...	Upside down		...		
				W of needle				
5.	...	...	...	N facing needle			45	12·9
6.	...	...	...	Upside down				
7.	...	...	...	S facing needle		45		
8.	...	...	...	Upside down		44·5		

Discussions—In placing the arms of the magnetometer at the magnetic east and west care should be taken that no magnets or magnetic substances are in the vicinity of the magnetometer, otherwise the magnetic needle would be affected and its position of equilibrium would be disturbed. A deflection of the needle near about 45° should be recorded, since an error in recording deflection near about this region involves least percentage of error. Of course if the bar magnet be too near the needle, then the uniformity of the field produced by the bar magnet is also effected. A compromise between these two factors should always be made by an inspection.

Date

EXPERIMENT 120

To Determine M/H using a Deflection Magnetometer from Tangent-B position

Theory—When the arms of a deflection magnetometer are placed along the magnetic meridian and bar magnet is kept at right angles to the arm such that the axis of rotation of the needle is on the line passing through the centre of the magnet at right angles to its magnetic axis, it is known as the Tan-B position of Gauss. In this position,

$$\frac{M}{H} = (d^2 + l^2)^{\frac{3}{2}} \tan\theta$$

where $2l$ = equivalent length of the bar magnet,
d = distance from the axis of rotation of the needle to the centre of the bar magnet,
$M = 2ml$ = magnetic moment of the bar magnet,
H = horizontal intensity of the earth's magnetic field,
θ = deflection of the needle.

Apparatus—A deflection magnetometer and a bar magnet.
[Give here a figure and description of a deflection magnetometer]

Procedure—Remove any magnet or magnetic material from the experimental table. Place the arms of the magnetometer parallel to the direction of the needle when pointers would read either 90° – 90° or 0° – 0° as the case may be.

Place the bar magnet alongside the metre scale and measure its length *thrice* at different parts of the scale correct to nearest millimetre or half millimetre; thus the mean geometric length is found, which is, suppose, l'. Then multiply l' by 0.9, which would give the equivalent length of the bar magnet. Suppose that it is $2l$. Measure also the breadth of the magnet in a similar way. Let it be b'.

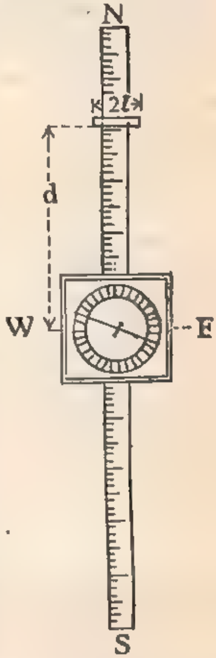


Fig. 223

Now, place the magnet at right angles to the length of the arm symmetrically as in Fig. 223, at such a distance that the deflection of the pointer is nearly 45°. Read the edge of the bar magnet facing the needle. The scale reading plus half the breadth of the magnet gives the distance d.

Keeping equal distance of the bar magnet to the north of the needle, take four readings of deflections for the following positions: (*i*) north pole of the bar magnet facing east, (*ii*) north pole facing east but the magnet turned upside down, (*iii*) north pole of the magnet facing west, (*iv*) north pole facing west but the magnet turned upside down.

Now take the bar magnet to the south of the needle at an equal distance from it and place it for all four positions given above and take readings. The mean of these deflections represents θ. Finally, make necessary calculations for M/H.

Mean geometric length of the bar magnet $= l'$

$\therefore$ Equivalent length of the bar magnet $= 0.9\ l' = 2l$

Mean breadth of the bar magnet $= b'$

No. of readings	Distance of edge $= d'$	Half of the breadth $= b'/2$	Distance $d = d' + b'/2$	Positions of Bar magnet	Half equivalent length $= l$	Deflection θ	Mean deflection	$\frac{M}{H}$
	cm.	cm.	cm.	Magnet north of needle	cm.	Deg.	Deg.	C.G.S.
1.	...	...	...	N pointing E				
2.	...	...	...	Turned upside				
3.	...	...	...	N pointing W				
4.	...	...	...	Turned upside				
				Magnet south of needle				
5.	...	...	...	N pointing E				
6.	...	...	...	Turned upside				
7.	...	...	...	N pointing W				
8.	...	...	...	Turned upside				

ORAL QUESTIONS

What is meant by M of a magnet? What is H? What is the origin of horizontal intensity? What is its unit? Suppose M/H of one magnet is greater than that of another; what conclusion you may derive from this? Why is a magnetometer needle very short? Distinguish between tan-A and tan-B positions. Can M/H be measured placing the magnetometer in any other position except at these two standard positions?

Date—

EXPERIMENT 121

To Compare the Magnetic Moments of two Magnets using Deflection magnetometer in Tangent-A position

Theory—If a bar magnet of moment M_1 and of length $2l_1$, placed at distance of d_1 form a magnetic needle in Tan-A position produces a deflection of θ_1°,

$$\text{Then } \frac{M_1}{H}=\frac{(d_1^2-l_1^2)^2}{2d_1}\tan\theta_1$$

H being the horizontal intensity of the earth's magnetic field.

For a second magnet of moment M_2 and of length $2l_2$ placed at a distance of d_2 form the same needle in Tan-A position producing a deflection of θ_2,

$$\frac{M_2}{H}=\frac{(d_2^2-l_2^2)^2}{d_2}\tan\theta_2$$

Thus combining the two equations, we get

$$\frac{M_1}{M_2}=\frac{(d_2^2-l_2^2)^2}{d_1}\times\frac{d_2}{(d_1^2-l_1^2)^2}\times\frac{\tan\theta_1}{\tan\theta_2}$$

Knowing d_1 l_1. θ_1, d_2 l_2, θ_2 the ratio of the magnetic moments can be determined.

Apparatus—A deflection magnetometer and a pair of magnets.

[A figure and description of a deflection magnetometer are to be given here.]

Procedure—Remove magnets and magnetic substances from the exprimental table. Place the arms of the magnetometer along magnetic east and west when the pointers of the needle are found to read 0°–0° or 90°–90° on the circular scale. For more detailed direction vide Expt. 119.

Take one magnet and measure its length three times; thus the mean geometric length is found. The equivalent length $2l_1$ of this bar magnet is 0.9×mean geometric length. Place the bar magnet *end-on* with respect to the needle at such a distance that the deflection of the needle is nearly 45° (Fig. 216). Read the position of the end of the magnet near the needle. To this add half the geometric length of the magnet and so get d_1. Again half the magnetic length of the magnet is l_1.

For the same distance of the bar magnet to the east of the needle take four readings of deflection *viz.* (*i*) north pole facing the needle, (*ii*) north pole facing the needle but the magnet turned

up-side down, (*iii*) south pole facing the needle, (*iv*) south pole facing the needle but the magnet turned upside down. Now take the magnet to the west of the needle and record a similar set of four readings. The mean of all these deflections is taken to be the deflection θ_1 of the needle.

Place the second magnet upon the magnetometer arm, the first one being removed to a considerable distance, and exactly take a similar set of readings with it. Let its equivalent length $=2l_2$, distance from the needle d_2 and mean deflection of the needle $=\theta_2$.

Results—

Mean geometric length of the first bar magnet $=l'_1=$

$\therefore$ equivalent length of the first bar magnet $=0{\cdot}9l'_1=2l_1$ or half the equivalent length $=l_1$.

Mean geometric length of the second bar magnet $=l'_2$

$\therefore$ equivalent length of the second bar magnet $={\cdot}9l'_2=2l_2$ or half the equivalent length $=l_2$.

Tabulation of data similar to that of Expt. No. 119 for each magnet except the last column M/H. Hence calculate M_1/M_2.

Discussions—The deflection of the needle in each case should be made near about 45° by altering the distance of the bar magnet from the needle. Because when the deflection is nearly 45°, the error in observation is minimum and the calculated result is most accurate. The magnetometer should be placed at the tan-A position as accurately as possible.

Date

EXPERIMENT 122

To Compare the Magnetic Moments of two Magnets with a Deflection Magnetometer in Tan-B position

Theory—If a magnet of moment M_1 and of length $2l_1$ placed at a distance of d_1 from a magnetic needle in Tan-B position produces a deflection θ_1,

$$\frac{M_1}{H}=(d^2{}_1+l^2{}_1)^{\frac{3}{2}}\tan\theta_1$$

H being the horizontal intensity of the earth's magnetic field.

For a second magnet of moment M_2 and of length $2l_2$ placed at a distance d_2 from the same needle in Tan-B position producing a deflection of θ_2.

$$\frac{M_2}{H}=(d_2{}^2+l_2{}^2)^{\frac{3}{2}}\tan\theta_1$$

Then combining the two equations, we get

$$\frac{M_1}{M_2}=\left(\frac{d_1{}^2+l_1{}^2}{d_2{}^2+l_2{}^2}\right)^{\frac{3}{2}}\times\frac{\tan\theta_1}{\tan\theta_2}$$

Thus knowing d_1, l_1, θ_1, d_2, l_2, θ_2, the ratio of the magnetic moments can be determined.

Apparatus—A deflection magnetometer and a pair of bar magnets.

Give here a figure and description of a deflection magnetometer].

Discussions—As in this experiment there is no question of deflection, the bar magnets may be placed anywhere on the magnetometer arms provided that the needle undergoes no deflection. The magnetometer should be accurately placed in tan-A position.

Date— EXPERIMENT 124

To Compare the Magnetic Moments of two Magnets by the Null method in Tangent-B position

Theory—If two bar magnets placed in broad-side-on position on opposite arms of a deflection magnetometer, produce no deflection of the needle, it is evident that the deflection produced by one is equal and opposite to that of the other. Let $\theta_1 = \theta_2$.

Then $\frac{M_1}{M_2} = \left(\frac{d_1^2 + l_1^2}{d_2^2 + l_2^2}\right)^{\frac{3}{2}}$

Knowing d_1, l_1, d_2 and l_2, the ratio M_1/M_2 can be determined.

Apparatus—A deflection magnetometer and a pair of bar magnets. [Give here a figure and description of a deflection magnetometer.]

Procedure—Remove magnets or magnetic substances from the experimental table. Place the arms of the magnetometer parallel to the axis of the magnetic needle, when the pointers are found to record $90°-90°$ or $0°-0°$ as the case may be.

Measure the actual lengths of the magnets three times correct to the nearest millimetre or half-millimetre and get their mean values. Four-fifths of these lengths give the equivalent lengths of the magnets. Let these be $2l_1$ and $2l_2$. Measure also the breadths of the magnets. Let these be b_1 and b_2.

Place one magnet at the broad-side-on position to the north of the needle as in Fig' 217 with its north pole facing *east* so as to get a considerable deflection of the needle. Then place the other magnet with the north pole facing *west* at the south of the needle almost at equal distance. Now adjust the distance of the second magnet to get no deflection of the pointer. Read the position of the nearer edges of the magnets.

Turn the first magnet upside down without altering the distance. Turn also the second magnet upside down and slightly adjust them to get the null position of the pointer. Read the nearer ends.

Place the magnets again with their poles in opposite directions and take the readings of their edges. Finally, turn both the magnet upside down and read their edges. Thus knowing the mean values of d_1 and d_2, calculate the ratio M_1/M_2.

Results—

Mean geometric length of the first magnet =
$\therefore$ equivalent length of the first magnet =

breadth of the first magnet =
Mean geometric length of the second magnet =
∴ equivalent length of the second magnet =
breadth of the second magnet =

No. of Readings	distance of edge $= d'$	half of breadth $= b/2$	distance $d = d' + b/2$	Position of Bar magnet	$\frac{1}{2}$ equivalent length $= l$	Ratio $\frac{M_1}{M_2}$
	cm.	cm.	cm.	First Magnet north	cm.	
1				N facing east		
2				Upside down		
3				N facing west		
4				Upside down		
				2nd Magnet south		
5				N facing west		
6				Upside down		
7				N facing east		
8				Upside down		

Discussions—The same as in the preceding experiment.

Oscillation of a Freely suspended Magnet in a Uniform Field

If a magnet, either pivoted or suspended, be kept inclined at a certain angle with a field of uniform intensity, then a mechanical couple acts upon it tending to bring it parallel to the original field. On releasing the magnet, it begins to swing under the action of this couple and by the time it becomes parallel to the field, the magnet develops sufficient angular momentum to swing past this position to the other side of the field. The magnet now moves against the couple and is, therefore, brought to rest when it has moved through a certain angle. From this position it again swings backwards due to the effect of the couple and thus periodic oscillation of the magnet persists.

EXPERIMENT 125

Date—

To Compare the Magnetic Moments of two Magnets with Vibration Magnetometer

(Separate Magnet Method)

Theory—If a bar magnet oscillates freely in a uniform magnetic field of intensity H,

Then $T_1 = 2\pi\sqrt{\frac{I_1}{M_1 H}}$

where T_1 = period of vibration or oscillation of the magnet.
I_1 = moment of inertia of the magnet about the axis of suspension,

M_1 = magnetic moment of the magnet,
π = a constant = 3·14,
H = horizontal intensity of the earth's field.

For another magnet oscillating in the same field.

$$T_2 = 2\pi\sqrt{\frac{I_2}{M_2 H}}$$

where T_2 = period of oscillation of that magent, I_2 = its moment of inertia about the axis of suspension and M_2 = its magnetic moment.

Hence $\dfrac{T_1}{T_2} = \sqrt{\dfrac{I_1 H_2}{I_2 H_1}}$ $\qquad \dfrac{M_1}{M_2} = \dfrac{I_1}{I_2} \times \dfrac{T_2^{\,2}}{T_1^{\,2}}$

Apparatus—A vibration magnetometer, a pair of magnets, stop-watch, a brass bar of nearly the same size as the magnet, a balance, a weight box, a simple callipers and a metre scale.

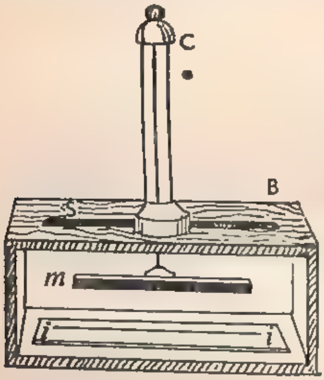


Fig. 224

A vibration magnetometer consists of a rectangular wooden box B having glass sides (Fig. 224). A vertical glass tube C provided with a torsion head is fixed at the middle of the box. The torsion head has got a small hook at which a thread of unspun silk fibre is fastened. The thread carries a stirrup at its bottom which can be seen through the glass sides. A long slit S is cut at the top of the box, through which observation can be made. The inside base of the box is provided with a strip of mirror on which a straight line i—i is etched.

Procedure—Level the box so that the suspension fibre becomes free. Mount the brass rod upon the stirrup so as to remain horizontal. If it oscillates freely the suspension fibre is torsion free. Remove magnets or magnetic substance from the table and suspend a magnetic needle freely near the box. Draw a chalk line on the table parallel to the axis of the needle. This line gives the magnetic meridian. Then slowly rotate the magnetmeter box so that the line etched on the plane mirror becomes parallel to the chalk line. Then rotate the upper torsion head so that the brass rod swings equally on either side of this line. The brass rod is then set parallel to the magnetic meridian.

Place a bar magnet on the stirrup so as to remain horizontal. To give it a small oscillation. bring a second bar magnet near the magnetometer box so that the inside magnet turns through a small angle not greater than 6° to 8°. Take away the second magnet. The magnet inside is found to oscillate. Observe the magnet through the slit and fix the eye at such a position that the image of the magnet in the plane mirror and the magnet itself appear to be coincident. Then there is no parallax error in recording oscillations of the magnet.

Then start the stop-watch and count 20 to 30 oscillations at the end of which stop the watch and record the interval for such oscillations. Take three such observations. Hence find the mean time for a single oscillation. Let it be T_1.

Take out the magnet and measure the mean geometric length of the magnet. Measure its breadth also. Find the mass of the magnet in a balance to the nearest decigram. The moment of inertia I of the magnet about the given axis is given by the formula, $I_1 = (a^2 + b^2)\ m/12$.

Exactly follow a similar procedure with the second magnet. Let its time period be T_2 as also its moment of inertia I_2. Finally, from the expression given already in theory, find the ratio of the magnetic moments of the magnets.

Results—

No. of readings		Time for 30 oscillations	Mean time for 30 osln.	Time for 1 oscillation	Mean Length of Magnet	Mean Breadth of Magnet	Mass of Magnet	Moment of inertia	Ratio M_1/M_2
		sec.	sec.	sec.	cm.	cm.	gm.	gm. cm.^{2}	
1st Magnet	1.	285							
	2.	...	285	9.5	10.2	1.5	8.06	717.3	
	3.	...							2.91
2nd Magnet	1.	...							
	2.	312	313	10.4	8.2	1.0	51.1	195.3	
	3.	...							

Discussions—In measuring the period of vibration of a magnet, the magnetometer box should be set accurately in the magnetic meridian and the suspension fibre should be made free from torsion. Total time for a fairly large number of oscillations should be reckoned by the watch.

Date— EXPERIMENT 126

To Compare the Magnetic Moments of Two Magnets by Vibration Magnetometer (Combined Magnets Method)

Theory—If two magnets of nearly similar appearance and of moments M_1 and M_2 be made to oscillate as one system with like poles in the same direction in a uniform field of intensity H.

$$\text{Then } T_1 = 2\pi\sqrt{\frac{I_1 + I_2}{(M_1 + M_2)H}}$$

where T_1 = period of oscillation of the composite magnet. I_1 and I_2 = moments of inertia of the magnets about the axis of suspension.

If again those two magnets be coupled with unlike poles pointing the same direction and made to oscillate in the same field.

$$\text{Then } T_2 = 2\pi\sqrt{\frac{I_1 + I_2}{(M_1 \sim M_2)H}}$$

where T_2 = period of oscillation of the new combination.

$$\text{Hence } \frac{M_1}{M_2} = \frac{T_1^2 + T_2^2}{T_2^2 \sim T_2^2}$$

Thus knowing T_1 and T_2 the ration of M_1 and M_2 can be found.

Apparatus—A vibration magnetometer, a stop-watch, a pair of bar magnets and a brass bar of nearly the same size as that of magnet. [Give here a figure and description of a vibration magnetometer.]

Procedure—Level the magnetometer base so that the suspension fibre does not touch any point of the vertical tube. Mount the brass rod on the stirrup so that it oscillates equally on both sides of the central line. The fibre is now free from torsion.

Then find the magnetic meridian with a magnetic needle or a bar magnet and set the base line of the magnetometer box parallel to the magnetic meridian.

Now place one magnet upon another so that like poles face same direction and tie them at two or three regions by knots of thin string. Mount the combination symmetrically on the stirrup and give small oscillations without any jerky movement.

Just when the combination passes over the central line in some direction start the stop-watch. Next time when it is passing over the central line in the same direction it makes one complete oscillation and count it as one. In this way, measure time for 20 to 30 oscillations. Take three such records of time and hence find the time period of a single oscillation. Let it be T_1.

Next form a new combination with unlike poles facing the same direction and tie these with strings. Find the period of the new combination in a similar way. Let it be T_2. Then from the formula find the ratio of M_1 and M_2.

Results

No. of reading	Combination with Like poles			Combination with Unlike poles			Ratio $\frac{T_1^2+T_2^2}{T_1^2 \sim T_2^2}$
	Time for 30 oscill. sec.	Time for 1 oscil sec.	Mean period T_1 sec.	Time for 30 oscill. sec.	Time for 1 oscill sec.	Mean period T_2 sec.	
1.							
2.							
3.							

Discussions—The same as in the preceding experiment.

Date—

Experiment 127

To Determine the Horizontal Intensity of the Earth's Magnetic Field

Theory—If a bar magnet of length $2l$ and of moment M be placed at a distance d in the Tangent-A position with respect to the needle of a deflection magnetometer and if the observed deflection is θ°,

Then $$\frac{M}{H}=\frac{(d^2-l^2)^2}{2d}\tan\theta$$

H being the horizontal intensity of the earth's field.

If again the same magnet be made to oscillate horizontally in the earth's field,

$$T=2\pi\sqrt{\frac{I}{MH}}$$

where T = period of oscillation, and I = moment of inertia of the magnet about the axis of suspension.

Combining the two equations, we get

$$H=\sqrt{\frac{8\pi^2\,Id}{T^2\,(d^2-l^2)^2\tan\theta}}=\frac{2\pi}{T(d^2-l^2)}\sqrt{\frac{2Id}{\tan\theta}}$$

Apparatus—A deflection magnetometer, a vibration magnetometer, a bar magnet, vernier callipers, a stop-watch, a balance and a weight box.

Procedure—Place the arms of the deflection magnetometer along magnetic east and west, when the pointers are found to read 0°—0° or 90°—90° of the circular scale; magnets or magnetic materials being removed from the table previously.

Measure the geometric length of the bar magnet with a slide callipers or a metre scale three times and find the mean length. The equivalent length $2l$ of the magnet is $0{\cdot}8\times$ geometrical length. Measure the breadth of the magnet in a similar manner.

Place the magnet on the eastern arm of the magnetometer with its axis pointing towards the pivot on which the needle of the magnetometer oscillates. The needle is found to be deflected. Observe the amount of deflection by the pointer. Now slide the magent on the arm at a suitable distance to get a deflection of nearly 45°. Read the position of the nearer end of the magnet on the scale attached. Take four readings for a given distance *viz.*; (*i*) north pole facing the needle, (*ii*) north pole facing the needle, the magnet turned upside down, (*iii*) south pole facing the needle, (*iv*) south pole facing the needle, the magnet turned upside down. Remove the magnet to the western arm of the magnetometer and place it likewise to get a deflection of nearly 45°. Read the position of the nearer end of the magnet. Take four readings of deflections for the given distance, as described previously. Finally calculate the mean value of all these deflections. Let the mean value be θ.

Next take a vibration magnetometer, place it parallel to the magnetic meridian (vide Expt. 125) In that position level it so that the suspension fibre does not touch any point of the vertical tube. Suspend a copper or brass rod on the stirrup and when the rod comes to rest, slowly rotate the torsion head to bring the rod parallel to the central line. The stirrup is then in the magnetic meridian.

Afterwards replace the rod by the bar magnet with its north pole pointing north and give it a very small oscillation, by another bar-magnet, the amplitude of oscillation not exceeding 7 to 8°. Observe the magnet through the slit from such a position that the image of the magnet and the magnet itself appear to be coincident. Just when the bar magnet passes over the central line in a definite direction start the stop watch and go on counting time for 30 complete oscillations and hence find the period for a complete oscillation.

Finally, measure the mass of the magnet in a physical balance correct to the nearest decigram. Hence calculate H from the formula.

Result—

Mean geometric length of the bar magnet = 13·0 cm. (say).

∴ Equivalent length of the bar magnet = 10·4 cm.

Mean breadth of the bar magnet = 1·4 cm.

Distance of the needle from centre of magnet = 15·6 cm.

To determine the mean deflection of the magnetometer needle, a tabulation as in Expt. 119 may be made; only the last column M/H is to be omitted.

Magnet east of needle				Magnet west of needle				Mean Deflection	tan θ
South pole near needle		North pole near needle		South pole near needle		North pole near needle			
Deg.		Deg.		Deg.		Deg.		Deg.	
45	44·5	44	44·5	44	44·5	44	44	44·5	·9827

To determine the period of oscillation of the magnet, a tabulation as in Expt. 125 may be made, only the last column M_1/M_2 is to be omitted.

The mean period of oscillation = 12·0 sec.
mass of the bar magnet = 70·22 gm.

$$\text{Hence } I = \frac{13^2 + 1.4^2}{12} \times 70.22 = 999.9 \text{ C.G.S units.}$$

$$\therefore \quad H = \sqrt{\frac{8 \times 3.14^2 \times 999.9 \times 15.6}{12^2 \times 15.3^2 \times .9827}} = 0.32 \text{ C.G.S. unit.}$$

Discussions—The suspension fibre of the vibration magnetometer should be torsion free, otherwise the equation for the period of the magnet as given in theory does not hold. The amplitude of

oscillation of the vibration magnet must also be small. Since the earth's field is uniform over a limited space, the magent may be regarded as placed in a uniform field of force.

The deflection of the magnetic needle of the magnetometer should be made nearly 45°; but to get such a deflection, if the bar magnet be required to be kept very near the needle, the uniformity of the field set up by the bar magnet is affected thereby. Hence a compromise between the deflection and the distance should be made. The mass of the magnet need not be taken correct to more than one place of decimals in grammes.

ORAL QUESTIONS

Why does a freely suspended magnet oscillate in the earth's field? If a magnet is taken to a stronger field and then made to oscillate, will its time period increase or decrease? Why? What is your idea about the moment of inertia of body? If a bar magnetis suspended edgewise or lengthwise, is there any change in the value of its moment of inertia? What is H and what is its unit? If you know H, what other thing you have to know to determine the resultant intensity of the earth's field?

Date—

EXPERIMENT 128

To Measure the Dip at a locality

Theory—Dip is the angle between the result line of force of the earth's magnetic field passing through a point and the horizontal plane passing through the point. Hence if a magnetic needle accurately pivoted at its centre of gravity be freely suspended in the magnetic meridian, the angle between its axis and the horizontal plane measures the dip at the point.

Apparatus—A dip circle and a spirit level.

A dip circle consists of a horizontal disc D supported on three levelling screws and having a circular scale graduated in degrees (Fig. 225) At the centre of disc there is a vertical metal pillar which can revolve and the amount of rotation can be read with a pointer attached to its base moving over the circular scale. At the upper end of the pillar there is a short magnetic needle M supported on a horizontal axis passing accurately through its centre of gravity. The needle is placed on agate pieces so that it can rotate in a vertical plane with as little friction as possible. To read the deflection of the magnetic needle there is a vertical graduated circle C fixed by the side of the needle. The needle with the graduated vertical circle is enclosed in a box provided with glass cover.

Procedure—Level the disc D at the base in the following way. Place the spirit level with its axis parallel to the line joining any two levelling screws. Work either one or both the screws along that line to bring the bubble at the centre. Then place the spirit level at right angles to its former position. Now work the third leveling screw to bring the bubble at the centre. The disc is levelled thereby.

Rotate the graduated circle along a vertical axis. The needle would be more or less deflected in a vertical plane. Continue the rotation of the vertical circle until the needle becomes vertical as is evident by 90° reading of the ends of the needle. At this position the influence of the horizontal intensity of the earth's field upon the needle becomes ineffective and so the plane of the graduated circle is perpendicular to the magnetic meridian. Read the position of the pointer over the graduated disc.

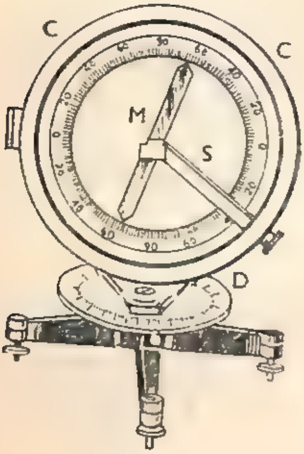


Fig. 225

Now, rotate the plane of the graduated circle through 90° as indicated by the pointer. The plane of circle as well as the plane of oscillation the magnetic needle are then in the magnetic meridian. The needle is found to point a particular direction. Read the ends of the needle on the graduated circle. Turn the needle upside down on bearings and take another set of readings. The mean of these four readings gives the inclination or dip at the place of observation.

Results—

Dip at Calcutta

No. of readings	Position of the End	Inclination	Mean Inclination
		deg.	deg.
1.	North Pole	29·5	
2.	South Pole	30·0	
	Needle reversed		29·5
3.	North Pole	29·0	
4.	South Pole	29·5	

Discussion—If the north pole of the dip needle is below the horizontal plane, it is customary to represent the inclination by N, otherwise the letter S is affixed. All over India the north pole of the dip needle is below the horizontal plane although by different amounts at different places. The dip at Calcutta is found to be 20·5°N. The dip at a locality undergoes a slow periodic change but it is very small and beyond the scope of measurement of ordinary dip circle. For accuracy in measuring the dip, the plane of rotation of the needle must be parallel to the magnetic meridian. The needle must be pivoted accurately at its centre of gravity and the magnetic axis should pass through the pointed ends of the needle.

Oral Questions

What are the magnetic elements of the earth? What should be the point of suspension of the needle? What happens if the needle is not accurately suspended at its centre of gravity? Why does a dip needle when properly set give the

inclination of a locality? Why is it that a magnetic needle can be set almost at all localities pointing vertically downwards? What is that position and why does it point vertical? At some locality on the Earth, the dip is found to be 90° what conclusion can be derived out of it? If the magnetic poles are not located accurately at the ends of the needle, how can it be used to find the dip at a place?

Date— EXPERIMENT 129

To Verify Inverse Square Law in Magnetism (Graphical Methods)

Theory—If two poles of strengths m and m' be placed at a distance r from each other, the mutual force between them is mm'/r^2. Hence for given pole strengths, the force varies inversely as the square of the distance.

Apparatus—A bar magnet, a short compass needle, drawing board and materials, two fixing pins, a divider and a metre scale.

Procedure—Remove magnets and magnetic materials from the experimental table. Place a compass needle, preferably a long one, on the table. Set apart two fixing long pins at a distance of about 2 ft. on the table and tie a thread with the pins at a height of about 6 in. such that the thread lies vertically above and parallel to the needle. The direction given by the thread is parallel to the magnetic meridian.

Fix the drawing paper on the drawing board and place the bar magnet at its middle part. Draw the outline of the magnet with a pencil. Place very short compass needle near one of its ends, when it is found to point that end. Now rotate the drawing board slowly till the needle becomes parallel to the thread. At this position mark the ends of the needle by two pencil dots. Find similarly two other positions of the needle and mark the ends by pencil dots. Join these three pairs of dots by straight lines which being produced meet at a point somewhere near the end of the outline of the magnet. This is the position of one pole. In a similar way, find the other pole (Fig. 226).

Place the bar magnet again within its outline on the paper and take point P at any convenient distance from the magnet, as shown in the figure. Place a *small* compass needle with its centre over the point. The compass needle will naturally point in the direction of the resultant intensity due to the magnet and the earth.

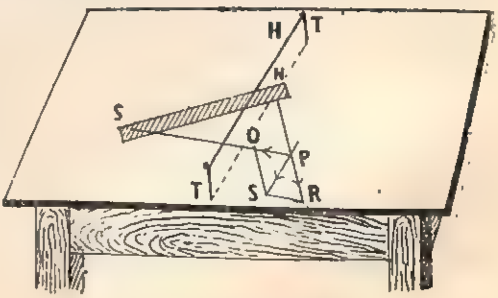


Fig. 226

Slowly rotate the drawing board to bring the compass needle parallel to the overhead thread. When the needle lies in the magnetic meridian, the action of the couple exerted by the earth's magnetic field on the magnetic needle vanishes and any deflection of the needle is due to the action of the bar magnet. Hence with regard to the point P, we may say that the direction of the resultant intensity due to the poles of the magnet is also the axis of the magnetic needle.

Mark the ends of the needle at this position by the pencil dots. Let the centre of the needle be P. Join the points and S by a straight line; similarly join N and P by another line which is produced beyond P Produce the line passing through the dots to a convenient point S. Taking PS as diagonal, complete a parallelogram PQSR. Thus the resultant force PS is equivalent to two forces PQ along PS and PR along NP. These two forces may be taken to represent the forces due to the south and north poles of the bar magnet acting on the magnetic needle.

If the strength of any pole of the needle be m' and any pole of the bar magnet be m and if the inverse square law is true,

Then $\dfrac{PQ}{PR}=\dfrac{mm'/mm'}{PS^2/PN^2}=\dfrac{PN^2}{PS^2}$

Hence if by actual measurement of lengths, the ratio of PQ to PR be equal to the square of the ratio of PN and PS, then the inverse square law is correct. Measure the distances PN, PS, PQ and PR with scale; hence verify in the inverse square law.

Take five or six such points evenly round the bar magnet and take similar observations.

Results—

No. of readings.	Distance PQ	Distance PR	Ratio PQ/PR	Distance PN	Distance PS	Ratio PN^2/PS^2	Percentage difference
	cm.	cm.		cm.	cm.		
1.							
2.							
3.							
4.							
5.							

Discussions—The point P is to be so selected that the distance PN or PS may not be too small or too large relatives to each other. Otherwise an error in reading either or both of them may produce a large error in the ratio of their squares. The magnetic needle used in the experiment should be short. Measurement of distance should be done as accurately as possible.

Oral Questions

What is inverse square law in magnetism? Why does a magnetic needle placed in a magnetic field point a definite direction? Define a line of force and state its properties. Why do you rotate the board so as to make the needle parallel the magnetic meridian?

Date—

Experiment 130

To Verify Inverse Square Law of Magnetic Forces by Deflection Magnetometer

(From Tangent-B position)

Theory—In the Tangent-B position of Gauss, if a bar magnet of length $2l$ and of moment M, placed at a distance d from the

magnetometer needle, produces a deflection θ, and if H be the horizontal intensity of the earth's field,

$$\text{Then } \frac{M}{H}=(d^2+l^2)^{\frac{3}{2}} \tan\theta$$

Since for a given magnet M is constant and for a given locality H is constant, then the left side expression is constant. Consequently the right side expression deduced from the theory of inverse square law, should also show a constant value.

Then the product of $(d^2+l^2)^{\frac{3}{2}}$ and $\tan\theta$ would be constant for various distances of the needle and so the graph between $(d^2+l^2)^{\frac{3}{2}}$ and $\cot\theta$ would be straight line.

Apparatus—A deflection magnetometer, a bar magnet.

[Give here description and sketch of a deflection magnetometer.]

Procedure—Remove magnets or magnetic materials from the experimental table, and set the magnetometer with its arms parallel to the magnetic meridian, when the pointers are found to read $0°-0°$ or $90°-90°$ of the circular scale.

Measure the length and breath of the bar magnet with a metre scale. Place the magnet on an arm in Tan-B position at a convenient distance to get a deflection of nearly 60° to 65° of the needle. Take the reading of the edge of the magnet. At this position take four readings of deflection in the following way: north pole of the magnet facing east; for the same position magnet turned upside down; north pole facing west; for the same position magnet turned upside down. Then move away the magnet from the needle and place it to such a distance that the deflection decreases by about 10°. Here also take a similar set of deflections. In this way take a record of the distance and deflection till deflection comes down to about 15° to 20°.

Results—Breadth of the magnet $=b=$

Mean geometric length of the magnet $=$

Equivalent length of the magnet $=2l=$

No. of readings	Distance $d+b/2$	Deflection θ				Mean $\theta°$	Tan θ	$(d^2+l^2)^{\frac{3}{2}}\times\tan\theta$
		N. pole east	Upside down	N pole west	Upside down			
1.								
2.								
3.								
4.								
5.								

Discussions—For a large value of θ the value of $\tan\theta$ is also considerably high and consequently the chance of making error is also greater. Hence the value of θ should not exceed 60° to 65°.

Frequency of Oscillations and Field Strength

It has been stated on page 354, that the time period T of a freely oscillating magnet in a field of uniform intensity H is given by the formula,

$$T=2\pi\sqrt{\frac{I}{MH}} \text{ whence } T^2 \propto \frac{I}{H} \quad \dots \quad (1)$$

If n be the frequency of oscillation of the magnet, then $1/n = T$

$$\therefore \quad \frac{1}{n^2}=T^2 \propto \frac{1}{H} \text{ whence } n^2 \propto H$$

If the magnet has a frequency of vibration n_1 in an increased field F_1+H and a frequency n_2 in another field F_2+H.

Then $F_1+H=kn_1^2$, also $F_2+H=kn_1^2$ and $H=kn^2$

$$\text{whence } \frac{F_1}{F_2}=\frac{n_1^2-n^2}{n_2^2-n^2}$$

Date— EXPERIMENT 131

To Compare the Field Strengths produced by two Magnets at a given distance from the Combination

Theory—If n be the frequency of oscillation of a *small* magnetic needle in the earth's horizontal field and if n_1 and n_2 be the frequencies of oscillation of the same needle when two horizontal field strengths F_1 and F_2 due to two magnets are separately superimposed on earth's field, then,

$$\frac{F_1}{F_5}=\frac{n_1^2-n^2}{n_2^2-n_2}$$

(For details vide Basu and Chatterjee's Intermediate Physics, Vol. II., Magnetism, Chap. IV, Art. 38).

Apparatus—Two bar magnets, metre scale, stop-clock, a short and stout magnetic needle with suspension arrangement or preferably Searle's vibrations magnetometer.

Searle's magnetometer consists of a small cylindrical magnet NS, nearly 1·5 cm. long and fixed at the lower part of a brass cylinder C (Fig. 227). The cylinder is supported vertically with unspun silk thread from a torsion head. There is an aluminium pointer PP fixed with the cylinder under the magnet. The purpose of the cylinder is to make the system heavy and of large moment of inertia to ensure a long period of vibration.

Procedure—Remove magnet or magnetic materials to a distance and suspend a bar magnet from a stand with unspun silk thread and a stirrup. When the magnet becomes steady, draw a chalk line on the table parallel to the longer edge of the magnet. This line gives the magnetic meridian.

Now suspend the magnetometer on the chalk line and rotate the torsion head to such a position that the pointer oscillates equally on both sides of the line. The magnetometer is now placed parallel to

the meridian. Let the magnetometer oscillate through a *small angle* pointing downwards and adjust the height of the magnet so that its north pole is on the *same horizontal plane* as that of the magneto-

Fig. 227

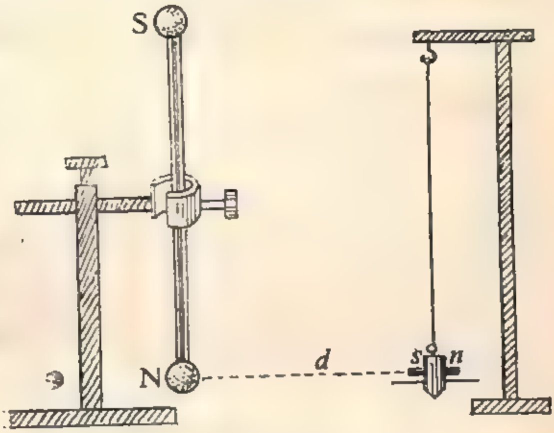


Fig. 228

meter (Fig. 228). Now place this vertical magnet *to the south of the magnetometer* at the given distance on the chalk line. The magnetometer is found to oscillate more rapidly. Determine by the stop-clock the interval for 20 oscillations. Let the mean frequency be n_1 at the given distance d from the centre of the needle to the north pole of the magnet.

Remove the bar magnet to some distance and place in a similar manner other bar magnet at the same distance. Count the interval of 20 oscillations and thence get the mean frequency of oscillation n_2. Then from the formula get the ratio of F_1 and F_2.

Results—

Distance between the north pole of the first bar magnet to the centre of the magnetometer needle = (*i*)............(*ii*)............cm.

∴ mean distance = ...cm.

No. of readings	Time for 20 oscillations			Time for single oscillation		
	Earth's field H	Magnet I + Earth's field (F_1+H)	Magnet II + Earth's field (F_2+H)	for H $=T$	for (F_1+H) $=T_1$	for (F_2+H) $=T_2$
	sec.	sec.	sec.	sec.	sec.	sec.
1.						
2.						
3.						

The second magnet kept at equal distance.

Hence $\frac{1}{T} = n =$ frequency of oscillation in Earth's field.

$\frac{1}{T} = n_1 =$ frequency of oscillation in the combined field due to 1st Magnet and Earth.

$\frac{1}{T_2} = n_2 =$ frequency of oscillation in the combined field due to 2nd Magnet and Earth.

$$\therefore \quad \frac{F_1}{F_2} = \frac{n_1^2 - n^2}{n_2^2 - n^2}.$$

Discussions—The magnetic needle used for the oscillation purpose should be short but it should have an appreciable moment of inertia. The two bar magnets whose fields are to be compared, should have equal lengths. They should be set vertical when comparing field strengths due to one pole of each and horizontal when comparing the field strengths due to both poles.

Oral Questions

Why do you use an unspun silk thread and not a spun silk thread for suspension? What is a field strength and what is it's unit? Why does the frequency of oscillation change with the field? Why do you not use a long needle for oscillation purposes? Suppose that you are experimenting in a room made of iron sheet, how do you expect the oscillation of your magnetometer to change?

CHAPTER VIII

EXPERIMENTS ON ELECTRICITY

Electrification

It is found that some substances such as glass, ebonite, polythene etc. when rubbed with silk or flannel acquire the property of attracting light substances such pieces of paper. This phenomenon is callen *electrification by friction.* The substance on which the attractive property is infused is said to be electrified or charged with electricity.

If a number of different bodies be electrified in this way, they can be distinctly divided into *two classes* by their mutual action upon one another. To classify them a glass rod rubbed with silk is suspended freely. Different substances rubbed with flannel, silk or fur, are brought successively near the rod. In some cases there is attraction ; in other cases a repulsion. Those that are repelled by the glass rod, also mutually repel one another. The kind of electricity generated on the substances repelled by the glass rod is called *positive* electricity. Hence positively charged bodies repel each other. An ebonite rod, rubbed with flannel, is suspended likewise. It is found to be attracted by the glass rod rubbed with silk or any other positively charged substance. The kind of electricity generated on ebonite by being rubbed with flannel is of opposite kind and is called *negative* electricity. Different substances rubbed with silk, flannel or fur, are brought successively near the ebonite rod rubbed with flannel ; those that are repelled are all negatively charged bodies. Thus there are two kinds of electricity, positive and negative.

Conductors and Insulators :

If a rod of ebonite be rubbed with flannel and held in hand, its charge can be examined for a considerable time in dry weather. But if a rod of metal be examined under a similar condition, its charge cannot be detected. The reason is that the charge developed on the metal by friction immediately goes to the earth through the body of the worker. But if the metal rod be provided with a dry wooden handle, the electricity on the metal remains localised and may be preserved for examination. Thus there are two distinct classes of substances,—the one class in which electricity cannot flow from one point to the other. These are called *non-conductors* or *insulators.* The other class in which electricity can flow from one part to the other called conductors. Glass, dry wood, procelain, ebonite etc. are insutators while metals, leather etc., are conductors. There is an intermediate class which allow electricity to pass through them with great resistance : these are called *partial conductors.*

Laws of Electrostatic Force :

It has already been stated that like charges repel and unlike charges attract each other. It is found that the force F between two electric charges of magnitudes q_1 and q_2 placed at a distance d is proportional to the product of the two charges and inversely proportional to the square of the distance between them.

Hence $F \propto \frac{q_1 \times q_2}{d^2}$ or $F = k\frac{q_1 \times q_2}{d^2}$

In the C.G.S. system of measurement a unit charge is defined to be a charge of such magnitude that when it is place one centimetre distance from a similar charge in air, the force between them is one dyne. According to this system of measurement, if $q_1 = q_2 =$ unit charge, and $d = 1$ cm. then F = 1 dyne. Thus the law of force reduces to $F = \frac{q_1 \times q_2}{d^2}$ (For further details vide Basu and Chatterjee's Intermediate Physics, Electricity, Chap. VIII).

Electrostatic Potential

The space surrounding a charged body, in which its influence upon other charged bodies can be detected, is called the *field of force* due to the chared body. A unit positive charge placed at any point in the field of force due to positively charged body experiences a force of repulsion. Due to the repulsive force the unit positive charge will move farther and farther from the charged body. The force exerted on a unit positive charge at any point is called the intensity of the field at that point. The intensity at any point has got some magnitude and direction; and hence it is a vector quantity.

If a unit positive charge is gradually brought nearer to a positively charged body, work is done continuously on this unit positive charge in the process of displacement. The amount of work done goes to increase the potential energy of the unit charge. As we displace the unit charge from point to point in the electric field there is in general a change in the total amount of potential energy. We may thus speak of *potential at a point is an electrostatic field* which measures the total amount of work done a unit positive charge to bring it from an infinite distance to the point under consideration. The potential gives the amount of work only and hence it is a scalar quantity. If the nature of the charge on the body is negative, the same definition for the potential at a point in its field will hold good; only the potential is negative in sign.

Since a unit positive charge tends to move from a positive charge to a negative one, we may say that *positive electricity moves* from a positive to a negative potential or more commonly *from higher to lower potential.* Conversely *negative electricity moves from lower to higher potential.*

The potential of a conducting body is defined to be the amount of work done in bringing a unit positive charge from infinity to a point *infinitely* near the surface of the conductor. The greater is the amount of charge on the body, the higher is its potential. The potential of a body is roughly guessed by the amount of deflection of the leaves of a gold-leaf electroscope when the body is taken near the disc of the instrument.

Electrostatic Capacity

The potential of a conductor increases with the amount of positive charge given to it. Thus, if Q be the amount of charge given to a conductor which is thereby raised to a potential V,

$$\text{Then } Q \propto V \qquad \therefore \quad Q = C \times V$$

where C is a constant depending upon the shape and volume of the conductor, nature of the medium surrounding it and the neighbourhood of other conductors. This constant is called the *capacity* of the conductor. Hence the capacity of a conductor may be measured by giving a known amount of charge to it and examining the rise of potential. A conductor has a capacity of one electrostatic unit when one electrostatic unit of charge raises its potential through one electrostatic unit. The practical unit of capacity is a *micro-farad* which is 9×0^5 times electrostatic unit of capacity.

Induction Machines

An electrostatic induction machine is a very useful apparatus in charging conductors for demonstrating experiments. The older types of statical electricity genetors are more of friction type for example a Voss machine. A more improved type is Wimshurst machine in which electricity is generated by a little of friction and much by induction. To collect electricity, the apparatus is to be warmed up in the sun or by a heater, so that the parts are dry. The apparatus is to be worked with charging knobs wide apart. The conductor with an insulating handle is to be touched with any of the knobs. If one knob charges it positively then the other would charge it negatively.

The best charging machine of modern time is a miniature Van de Graff generator, which is purely an induction machine. It needs little preheating for an operation. The details regarding all these machines are given in Basu and Chatterjee's Intermediate Physics in Part II Electricity.

Date— **EXPERIMENT 132**

To Charge and Discharge a Gold-leaf Electroscope

Apparatus—Gold-leaf electroscope, ebonite and glass rods, silk and flannel pieces, a brass rod mounted on a varnished glass handle, and ordinary or a shelf oven for keeping apparatus dry and a metal plate.

There are varities of forms of the gold-leaf electroscope. In one form, used mainly for demonstration purposes, it consists of a brass rod R having at its upper end a brass disc D (Fig. 229). At the lower extremity of this rod a very thin light leaf of gold L is attached. The rod passes into a metal ring M, the mouth of which is tightly stoppered by some nonconducting material. The front and back faces of the ring are covered by two glass plates. A basin containing calcium chloride or small pieces of pumice stone soaked with strong sulphuric acid is placed inside to keep the air dry. Another sensitive type of a gold leaf electroscope is shown in Fig. 230. For description vide Basu and Chatterjee's Intermediate Physics, Statical Electricity, Chap. I. Vol. II.

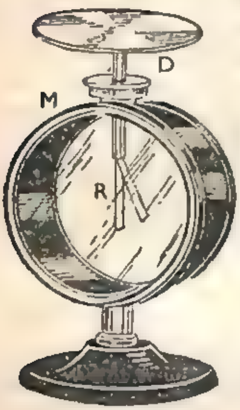


Fig. 229

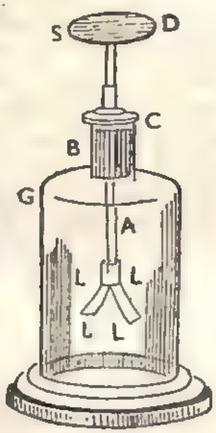


Fig. 230

Fig. 231

To charge an Electroscope by Conduction—Mount a brass rod on the glass handle and dry the combination thoroughly on the oven. Place the electroscope on the table after drying it thoroughly. Then hold the rod by its glass part, care being taken not to touch the metal part. Flap gently the brass rod with silk or catskin and place it before the brass disc of the electroscope without touching it. A view of the catskin and the rod is given in Fig. 231. If the divergence of the leaf appears to be too large, reduce the charge of the brass rod partially by touching it with the brass portion of a similar rod. Then make the brass rod touch the disc of the electroscope when a divergence of the leaf, is observed. The electroscope is thus charged positively by conduction.

To charge an Electroscope by Induction—Rub thoroughly dried ebonite rod with silk and hold it a *little above* the disc of the electroscope. The leaves are found to diverge. Without removing the rod, touch the disc *momentarily* with a finger, when the leaves collapse. Next take away the rod and the leaves again diverge. The electroscope is thus charged by induction.

To observe the nature of the charge on the electroscope bring a glass rod charged *positively* by rubbing with silk, near the disc of the electroscope. The divergence of the leaves is found to increase. Hence the electroscope is charged positively by induction. Since this charge is produced by an ebonite rod charged *negatively* by rubbing with silk, we may infer that opposite *electrification is developed by induction.*

ORAL QUESTIONS

Distinguish between electrostatic induction and conduction. Why are the leaves of the electroscope very thin? Why do you warm the apparatus before experiment? Why is the brass rod mounted on the glass handle? Why a metal case is kept around the leaves?

Date— EXPERIMENT 133

To Show that a Potential Difference is responsible for Divergence of the Leaves

Theory—When a difference of potential is maintained between the leaves of the electroscope and its walls, there is a tendency of the positive charge to flow from a region of higher potential to a region of lower potential until potentials are equalised. Negative charges tend to move in the opposite direction. The forces, acting on the charges of the leaves, manifest as the divergence of the leaves.

Apparatus—A gold-leaf electroscope, ebonite and glass rods, insulating stand, drying oven etc.

Procedure—(i) Warm and dry the electroscope and its accessories in sun light or electric heater for about half an hour before proceeding with experiment. Place the electroscope on the table and connect its base by a wire to the earth. This can be done very efficiently by connecting the end of wire to the gas or water pipe. The potential of the base and inside tin foils is then zero.

Rub an ebonite rod with flannel to charge it negatively. With this rod charge the disc of the electroscope positively by induction. Observe that the leaves diverge. Discharge the electroscope by momentarily touching its disc with a finger. Now rub a glass rod with silk and charge the electroscope negatively by induction. Observe that the leaves again diverge. This shows that if the base is kept at a zero potential, any kind of charge on the *insulated* disc produces a divergence.

Again connect the base and the disc by another wire, while the base is earthed. Now bring near the disc an ebonite rod rubbed with flannel or a glass rod rubbed with silk. Observe that in either case there is no divergence of the leaves. This proves that if the disc and the base are at zero potential, there is no divergence.

(ii) Insulate the base by placing the electroscope on a plate made of sulphur or some other insulating material and cutting off the wire connection. Make the disc earth-connected. Charge the base either positively or negatively by induction. In either case leaves are found to diverge. This proves that when the insulated

base is charged, there is a divergence of leaves even if they are kept at zero potential.

Make the outer casing of the electroscope earthed along with the disc. Bring a charged body, either positive or negative near the disc. Observe that there is no divergence. So when both are at zero potential there cannot be any divergence.

(iii) Connect the base and the disc by a wire, so that they are always at the same potential. Charge the disc either positively or negatively. There is little or no divergence. Now remove the wire connection of the disc with an insulating handle and touch either the base of the disc. So, there is a potential difference between the disc or leaves and the base. In either case the leaves diverge.

Results—

Experiment		Potential of the base	Potential of the leaves	Observation
Base earthed	leaves +ly charged	0	+	divergence
	leaves—ly charged	0	—	do
	leaves and base connected	0	0	no divergence
Leaves earthed	base +ly charged	+	0	divergence
	base—ly charged	—	0	do
	leaves and base connected	0	0	no divergence
Electroscope on insulating stand	both +ly charged	$+V_1$ (say)	$+V_1$	no divergence
Base and leaves connected	both—ly charged	$-V_2$ (say)	$-V_2$	do
Electroscope on insulating stand	Leaves earthed	+	0	divergence
Base and leaves charged +ly and then disconnected	Base earthed	0	+	do
do	Base earthed	0	—	divergence
Base and leaves —ly charged and then disconnected	Leaves earthed	—	0	do

Discussions—From the above observations it is evident that the divergence of the leaves of the electroscope does not depend on the absolute value of the potential of the leaves, but always on the difference of the potentials of the leaves and the case which surrounds the leaves.

Date—

EXPERIMENT 134

To Study the Effects of Electrostatic Induction

Theory—The electrification acquired by a conductor due to the presence of an electric charge in its neighbourhood and not actually in metallic contact is called electrostatic induction.

Apparatus—A gold-leaf electroscope, glass and ebonite rods, two insulated metal balls of equal size, a brass rod mounted on varnished glass handle, fur and silk pieces, drying oven etc.

Procedure—*To charge a metallic body by Induction*—Dry thoroughly all the apparatus in the oven. Suspend from a vertical stand a metal ball with silk or nylon thread. Rub an ebonite rod with silk and place it before the ball. Touch the ball momentarily with finger and then take away the rod.

Examine the nature of the charge of the ball with an electroscope charged positively. An increased divergence indicates that the ball is charged positively by induction. Examine the nature of of the charge on the ebonite rod with the electroscope charged negatively. The divergence increases showing that the inducing charge is negative. Hence *a charge of opposite nature is developed by induction.*

(ii) *To show that equal and opposite amount of electricity is developed on the induced body*—Suspend by silk thread two metal balls of equal size from two vertical stands and place them touching each other. Rub the ebonite rod with silk and place it before the combination. In presence of the ebonite rod the two balls are separated by holding the insulated part. The nature of the charge of each ball is examined with an electroscope. One is found to be charged positively and the other negatively.

Now make the two balls touch each other and then examine the nature of charge. They are found to be completely discharged. Hence their charges are equal and opposite.

(iii) *To show that in general inducing charge is greater than the observed induced charge*—Charge one of the insulated balls positively either by flapping with a piece of flannel or by connecting directly with an influence machine. Take the other ball near the charged ball and touch it with finger. Examine the nature of the charge on the induced body; it is found to be negative.

Make the two balls touch each other, and examine the nature of the charge of each ball. Each is found to be *feebly* positively charged. This proves that the positive charge of one ball was in *excess* of the negative charge of the other ball, so that when they were connected, the *excess* positive charge was distributed over the two.

Date— EXPERIMENT 135

To Show that the induced Charge is equal to the Inducing Charge

(Faraday's Ice pail Experiment)

Theory—When the body on which the charge is induced, is so placed as to cover the inducing charge on all sides, the induced charge may be shown to be equal to the inducing charge.

Apparatus—An electroscope, a metal ball suspended by silk thread, a deep hollow metal can, an influence machine or any other charging appliance, drying oven etc.

Procedure—Dry the metal can very thoroughly and place it on the disc of the electroscope; if any divergence of the leaves is

noticed, touch the can with finger so as to completely discharge it, when the leaves collapse.

Suspend the ball, previously dried in oven, by thread from a stand and make it touch the prime conductor of a friction machine. It receives some charge. The machine should be kept at a considerable distance from the electroscope to avoid any inductive action.

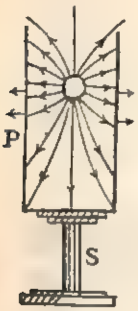


Fig. 232

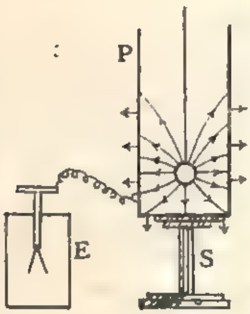


Fig. 233

Remove the ball by thread and slowly lower it into the hollow of the can without touching its sides. The divergence of the leaves is found to increase more and more (Fig. 232). when the ball is taken near the bottom, the divergence reaches a maximum value. Now move the ball to different sides and observe that the divergence does not change proving thereby that the charge induced on the can is maximum (Fig 233). The lines starting from the ball indicate lines of force when it is positively charged.

Make the ball touch the bottom of the can. There is no change in the divergence of the leaves. Take the ball out Remove the can from the disc and discharge the electroscope. Bring the ball to the uncharged electroscope and observe no divergence. Repeat the experiment a number of times, but in every case you will find that the ball when taken out of the can after touching its base exhibits no electrical charge.

Inference—Let the ball acquire a charge q_1 from the machine in any one experiment. When lowered *deep* into the can, let the charge induced on the inner walls of the can be $-q_2$. If possible, let $q_1 > q_2$, so that when the ball touches the bottom, the whole of the positive charge of the ball is not neutralised, and the excess $q_1 - q_2$ is distributed over the outer surface of the can to increase the divergence of the leaves. But since there is no change in divergence of the leaves, q_1 cannot be greater than q_1 nor less. Hence the inducing charge in this case is equal to the induced charge.

Date—

EXPERIMENT 136

To Study the Action of an Electrophorus

Apparatus—An electrophorus, flannel or catskin, insulated metal ball, proof plane, gold-leaf electroscope and drying over etc.

An electrophorus is an electric machine to get a large intermittent supply of electric charge. It consists of a vulcanite or resin cake C placed on a metal dish D, called the sole. A brass disc just

fitting the cake, called the cover P, is provided with an insulating handle H (Fig. 234).

Procedure—Warm and dry the cake, dish and the sole in the oven. Place the cake on the sole on a table and thoroughly rub the cake with flannel or catskin. Hold the cover by the insulating handle on the cake and touch the cover momentarily with finger. Then lift the cover by the handle and slowly bring it near the disc of an uncharged electroscope. Observe that the leaves diverge which proves that the cover is electrically charged.

To investigate the nature of the charge on the cover plate, charge the electroscope positively and slowly bring the cover near the electroscope from a distance of 3 to 4 ft. An increased divergence indicates that the cover is also positively charged. Discharge the cover by touching with finger and again place it on the cake. Touch the cover *momentarily* with a finger and lift it. Take it near a positively charged electroscope and observe that leaves diverge. Hence it is possible to get a large supply of positive charge by flapping the cake once for all.

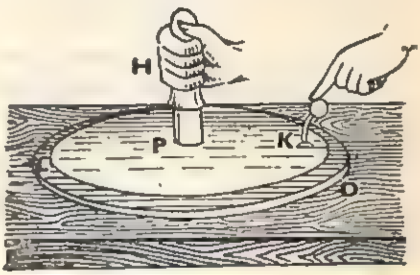


Fig. 234

Again, place the cover on the cake and touch it momentarily. Without removing the cover, touch it with a proof-plane and bring the proof-plane before an uncharged electroscope. Observe that there is no divergence of the leaves. Various forms of proof-plane are shown in Fig. 235. The experiment shows that the proof-plane cannot receive any charge when the cover is in contact with the cake. Lift the cover to some height and touch the proof-plane with it and bring it before the same electroscope. Now a divergence is noticed. Hence we may conclude that the electrical energy of the system appears only when the cover is separated from the cake which is oppositely charged. Since a proces of separation against an attractive force requires expenditure of some work, it is concluded, that this work increases the electrical energy of the cover.

Fig. 235

Flow of Electricity

Take two conductors of large size and charge one of them positively and the other negatively, carefully keeping each one of them on insulating stands. Connect one of them by a wire to a knob type small electroscope and observe the amount of deflection of the leaves. The deflection gives a measure of electrostatic potential of one conductor. Find in a similar manner the potential of the other conductor. The two potentials are of opposite characters

and may be of different magnitudes, since in one case the electroscope would be charged positively and in the other case it would be charged negatively. Now momentarily connect the two conductors by a wire and examine the nature of potential of the combination. It would be found on connecting the same electroscope, that the deflection is much less this time and is equal for the two showing that both of them have acquired the same potential. Such an equalisation of potential may be explained by assuming that the negatively charged electrons have moved through the conducting wire from one at the lower potential to the other at the higher to equalise the potential. Such a passage of electricity between two electrified bodies is called an electric current. If an arrangement be devised such that the two connected conductors be supplied with charges at the same rate at which they lose the charge, they may be kept at a constant difference of potentials, the flow of electricity becomes persistent and a uniform current is obtained in the wire. This is practically attained in a voltaic cell in which the two electrodes are always kept at a finite difference of potentials. For theory of contact potential in a Voltaic cell vide author's Intermediate Physics.

In gases and solutions the electric current is produced by the movement of positive and negative charges (ions) in opposite directions along the electric field. But in solid conductors the nuclei of the atoms which are the sources of positive charges are held together firmly and they cannot move. The electrons move in procession from the lower to the higher potential producing the current. (For details vide Basu & Chatterjee's Intermediate Physics, Electricity, Chap. XI).

A Simple Voltaic Cell

A simple voltaic cell consists of a zinc plate Z and a copper plate C partially immersed in dilute sulphuric acid in a glass or earthenware pot (Fig. 236). The two plates are then permanently kept at two different potentials: the copper at a higher potential and zinc at a lower one.

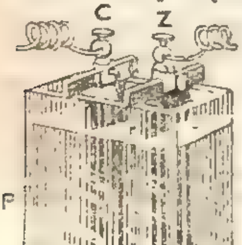


Fig. 236

On now connecting a metallic wire between the two plates an electric current flows through the wire: electrons moving through the wire from zinc to copper plate. The difference of potentials between the copper and zinc plates tends to diminish due to the flow of charge but the contact potential difference between copper and acid as also between acid and zinc remains constant and, therefore, current persists so long as chemical action goes on.

According to the theory of electrolytic dissociation some of the sulphuric acid molecules in solution break up into two parts, each part being electrically charged. One neutral molecule of H_2SO_4 breaks up into two H-ions which are positively charged and a SO_4-ion which is negatively charged. These two oppositely charged ions are very loosely bound within the solution. As

soon as the two plates are dipped into the solution, an electrical field due to the contact potential difference is established between the plates. Consequently these two charged systems of ions move in opposite directions setting up a field just equal and opposite. The cell is now in equilibrium state. If now a wire is connected between the two plates the ionic charges developed on the two plates tend to neutralize by flowing through the wire. As soon as a part of the charges has been neutralized, more and more ions begin to deposit their charges on the plates due to internal field. In this way a continuous current is established through the external wire. (For a detail study of mechanism of transport of charges through a cell, vide Basu & Chatterjee's Intermediate Physics, Electricity. Chap. XI).

The chemical action occuring within a cell is as follows:

$$Zn + H_2SO_4 = ZnSO_4 + 2H$$

Defects of a Simple Cell

There are two principal defects of a simple cell preventing a continuous flow of electric current through it. These are (i) local action and (ii) polarisation.

Local action—Ordinarily zinc available in the market contains many impurities *e.g.*, iron, lead etc. If any one of such impurities lies on the surface of the zinc rod used in a cell, a minute cell is formed consisting of zinc rod, acid and the impurity. Thus a current called the local current flows on the zinc rod within the cell. The particles of impurities being numerous, many such minute cells are formed causing an unnecessary wastage of zinc, both when the circuit is open or closed. This is called the local action. Local action may be demonstrated by dipping an impure zinc rod in sulphuric acid when bubbles of hydrogen and oxygen are given off from the rod.

Fig. 237

To prevent the local action the zinc rod is first washed with dilute sulphuric acid and then rubbed thoroughly with mercury. A layer of mercury sticks to the zinc surface forming a coat all around. This layer of mercury dissolves zinc which floates on its outer surface while impurities remain inside the coat. Thus zinc only comes in contact with the acid solution and is acted upon by it. This process of forming a coat of mercury on zinc is called amalgamating the zinc.

Polarisation—When a current flows in a simple cell bubbles of hydrogen gas are evolved at the copper plate. In the process of evolution of the bubbles a thin film of gas is gradually formed on the copper plate, which continuously decreases the strength of the current and stops it altogether after sometime. This is called the polarisation. Polarisation may be demonstrated in a cell by connecting an electric bell, which works all right from the start but stops ringing after a few minutes.

The deposition of hydrogen film may be prevented either by mechanical means or by chemical means. In the mechanical procedure the copper plate is taken out at intervals and brushed off to remove hydrogen film. This method is troublesome and also imperfect. In chemical method the evolved hydrogen is converted chemically into some other substances not interfering with the flow of a continuous current. The chemicals used to remove hydrogen are called depolarisers.

Date—

EXPERIMENT 137

To Set up a Daniell's cell

Apparatus—A copper vessel with a perforated shelf, a porous pot, a zinc rod, two binding screws, some quantity of mercury and crystals of copper sulphuric acid.

A Daniell's cell consists of a cylindrical copper vessel provided with a annular perforated shelf near its top (Fig. 238). A porous cylindrical pot is placed within the copper vessel and the space between the two is filled almost to the top with a saturated solution of copper sulphate. The perforated shelf contains crystals of copper sulphate. The porous pot is filled with a dilute solution of sulphuric acid in which a rod of amalgamated zinc is partially dipped. The outer copper vessel and the zinc rod are fitted with binding screws.

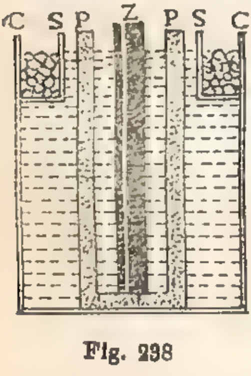


Fig. 238

Procedure—Wash the zinc rod with dilute sulphuric acid. Take a shallow trough and place the zinc rod on the trough. Then take a little mercury on your palm and rub the rod gently. Take a quantity of water in a glass beaker. Add sulphuric acid to water drop by drop until the proportion of acid added is about one tenth the volume of water. While acid is being added stir the mixture slowly. Prepare also a saturated solution of copper sulphate by mixing an excess of powdered copper sulphate crystals with distilled water.

Place the zinc rod within the porous pot and fit a clip with a binding screw to its top. Pour the sulphuric acid solution into the porous pot upto its brim. Pour also the copper sulphate solution into the space between the porous pot and the copper vessel so that the perforated shelf is partly immersed in the liquid. Place a few crystals of copper sulphate on the shelf. Fit another clip with a binding screw with the copper vessel. The cell is now ready for use.

Connect the terminals of a 2-volt lamp to the two binding screws; the lamp glows a little showing that current flows through it; the copper vessel being the high potential plate and zinc the lower one. Sulphuric acid solution is the exciting liquid and copper sulphate solution is the depolariser. The chemical action within the cell is follows:

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$
$$CuSO_4 + H_2 = Cu + H_2SO_4$$

The current passing through the wire may be detected by any one of its effects e.g., magnetic, chemical or heating.

Discussions—The two plates of the cell should not be connected by a thick wire which has very negligible resistance for in this case a heavy current passes through the wire injuring the life of the cell. This is called short-circuiting the cell, which is always to be avoided. The hydrogen evolved chemically acts upon copper sulphate to deposit copper on copper plate. In this manner polarisation is avoided. When the cell is not in use, the acid and the depolariser should be taken out and the vessel should be washed with water. This is called dismantling the cell. The E. M. F. of a Daniell's cell is very nearly 1·07 volts which can be examined with a voltmeter.

ORAL QUESTIONS

Describe a Daniell's Cell. What is the procedure adopted to minimise the local action and polarisation within this cell? What is the e. m. f. of such a cell? What are the uses of such a cell? What is the source of energy in a cell? What is short-circuiting a cell? How is a cell injured when short-circuited? How would you connect a number of cells when you want higher e.m.f. or a higher current?

Date— EXPERIMENT 138

To Set up a Leclanche's cell

Apparatus—A wide glass bottle, a zinc rod, a quantity of mercury, ammonium chloride, a carbon rod, charcoal, powdered manganese dioxide and a porous pot.

A Leclanche's cell consists of a glass bottle P containing a strong solution of ammonium chloride (Fig 239). An amalgamated zinc rod Z is partially immersed in the solution. A porous pot containing a rod of gas carbon C stands almost at the middle of the bottle. The space between the carbon rod and the porous pot is closely packed with a mixture of charcoal and powdered manganese dioxide.

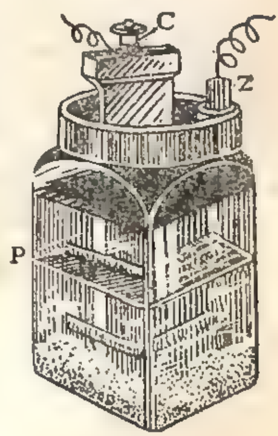


Fig. 239

Procedure—Wash the zinc rod with dilute sulphuric acid and place it over a flat trough. Now rub the rod with a little mercury. Prepare a saturated solution of ammonium chloride by mixing sufficient quantity of ammonium chloride in water. Place the rod of gas carbon within the porous pot and tightly pack a mixture of powdered manganese dioxide and carbon around it. Place the porous pot in the solution Fix two binding screws to the carbon and zinc rods. The cell is now ready for use. On connecting a small bulb, it is found to glow, showing that the cell is sending a current.

Carbon rod forms the high potential plate and zinc rod the low one. Ammonium chloride solution is the exciting liquid and manga-

nese dioxide is the depolariser. The chemical action going on within the cell when the current is flowing is as follows:

$$Zn + 2NH_4Cl = ZnCl_2 + 2NH_3 + H_2$$
$$H_2 + 2MnO_2 = Mn_2O_3 + H_2O$$

Discussions—The depolariser in this case is solid and hence the rate at which hydrogen is oxidised is rather slow. Therefore, when such a cell is continuously worked for sometime a considerable amount of hydrogen is evolved which produces a partial polarisation of the high potential plate. For this reason this cell is very suitable for an intermittent supply of electric current as required in an electric bell, telephone etc. The E.M.F. of the cell is 1·4 volts.

Testing the Polarities of Cell

Either the magnetic or the electrolytic effect may be employed to determine the direction of current in an electrical circuit. The terminals of a cell are connected by a wire stretched over a supended magnetic needle. Then observing the deflection of the N-pole and applying the Ampere's swimming rule, the direction of current flow can be determined and hence the nature of the polarity of the cell is known. There is another way of examining the polarity. A trough containing some water is taken and one or two drops of sulphuric acid added to it. Two wires are connected to two electrodes of the cell and the other ends of the wires are dipped into the solution. Hydrogen is evolved at the negative electrode and oxygen at the positive. But hydrogen being more profusely produced than oxygen, bubbling is noticed more prominently at the negative terminal. But in testing the electric supply mains if the terminals are put in acidulated water, the current through the solution is so large that it would form a spark and the circuit line will be fused. Pure water is to be taken instead of acidulated water, because pure water, being a bad conductor of electricity would carry a feeble current through it.

Accessories for Electrical Experiments

There are a few auxiliary apparatus, which are found to be indispensably necessary in one or other electrical experiments. These are described below.

Binding Screw—It consists of a metallic piece having screw thread and a nut working on it. The metal piece is fixed rigidly with the body to which electrical connection is to be made. The wire conveying the current is made into a loop and fixed with the nut.

Connectors—There are metallic pieces having two clamping screws or springs at two ends. These are used to connect two wires at a single point or for connecting a wire with a thin rod or plate etc.

Plug Key—It consists of a rectangular base B made of ebonite or bakelite, on which two metallic pieces are fixed. These two pieces are provided with two binding screws SS and are separated

from each other by a small air gap (Fig. 240). A cylindrical brass piece with an ebonite cap P just fits into the gap and thereby makes a metallic contact between the two pieces. A plug key is always used in an electrical circuit which requires to be opened or closed

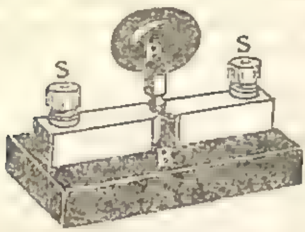


Fig. 240

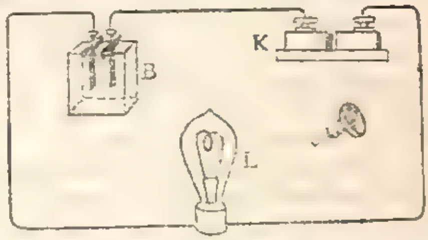


Fig. 241

whenever desired. The manner in which a plug kep is connected in a circuit is shown in Fig. 241 containing battery B and a flash-light bulb L. One terminal of the battery is connected to one of the binding screws of the key and the other terminal is connected by another piece of wire to the bulb and then to the other bindind screw. If now the key P is taken out, the two pieces of wires are disconnected and the current is stopped in the circuit. When the plug is inserted the wires are in contact and current flows.

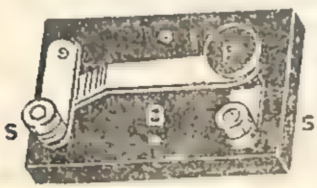


Fig. 242

Tapping Key—It consists of an ebonite base B on which two metallic pieces having binding screws SS are fixed (Fig. 242). With one piece is fixed a metallic spring having a non-conducting button P. In the normal condition the spring does not touch the other binding screw, but when the button is pressed a connection is established between the metallic pieces. On releasing the pressure the spring jumps up and the connection is severed. It is used for making an instantaneous electrical contact. The method of connecting a tapping key in an electrical circuit is identical with that of a plug key.

Plug Commutator—It consists of four uniform metallic pieces BB GG fixed on an ebonite base and insulated from each other by

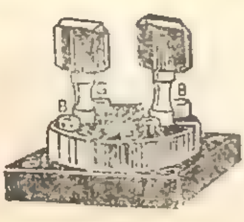


Fig. 243

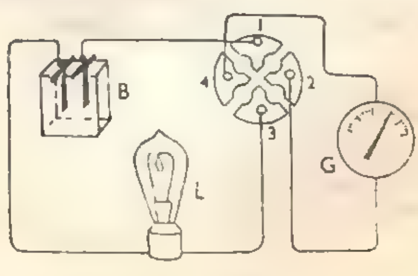


Fig. 244

small air gaps (Fig. 243). Each metallic piece is provided with a binding screw to which a wire can be connected. There are two

plugs by which connection can be established between any two pieces. The plugs are always inserted *diagonally*. It is used to convey current through any part of an electrical circuit and to reverse the current in that circuit whenever required. The leads from the battery circuit are connected to the screws BB and the two terminals of the circuit under examination are connected to the screws GG. For two positions of diagonal insertion of plugs the current is led in opposite directions.

Fig. 244 shows the manner of using a plug commutator in a circuit containing a battery, a lamp and a galvanometer. Note that terminals of the battery and galvanometer are connected *diagonally* at the commutator having numbers 1, 2, 3 and 4. If sectors 1 and 3 represent the +ve and −ve terminals of the battery respectively and if plugs are put between 1 and 4, 2 and 3, then current flows within the galvanometer from sector 4 to sector 2. Whereas if plugs are put between 1 and 2, 3 and 4, current flows within the galvanometer from sector 2 to 4. Thus current is reversed.

Pohl's Commutator—It consists of an ebonite base provided with six small holes each containing mercury (Fig. 245). Mercury in each hole is connected by a wire through the base to a separate binding screw by its side. The four holes on the two opposite sides of the block are diagonally connected by two pieces of wires forming a cross on the underside. There in a metallic rider, called the jockey J, having six legs fittings into the six mercury cups. The jockey rests on the cups in such a way that when its two legs rest upon two mercury cups at BB, the other to legs just opposite to them rise above the other cups are disconnected. The two other legs at CC are permanently connected to the jockey. The battery terminals are connected to BB and the circuit under examination to CC. On rocking the jockey from one side to other, the current in the circuit is reversed.

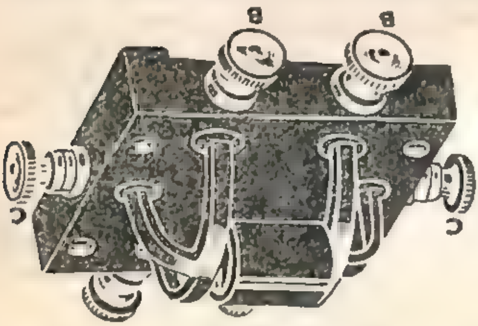


Fig. 245

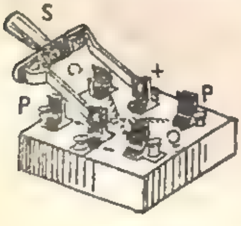


Fig. 246

Fig. 247

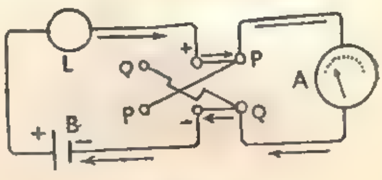


Fig. 248

Another form of commutator is shown in Fig. 246, which consists of a non-conducting plate having six metal plugs fixed to it. The

two extreme plugs are diagonally connected by metal wires as shown by PP and QQ. A knife switch S hinged to the middle plugs can work either side. The switch put to the left is shown diagrammatically in Fig. 247. The battery circuit is connected to the middle pair of plugs and the current reversing circuit to any one pair of P and Q.

The actual manner of connecting a battery circuit containing a lamp L and a reversing circuit containing a galvanometer A is shown in Fig. 248. The positive terminal of the circuit is connected to the upper middle plug. When the knife switch is placed to the right side, note that the current flows through the galvanometer circuit from top to the bottom. If however, the switch is placed to the left the current flows through the galvanometer in the reverse direction.

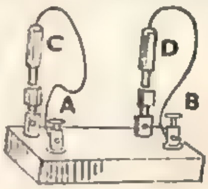


Fig. 249

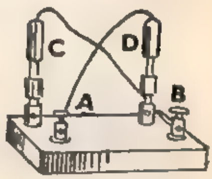


Fig. 250

A third form of commutator is shown in Figs. 249 and 250. It consists of a non-conducting base with four terminal binding screws A, B, C and D. Connections by wire may be established by prod and socket arrangements between A and C, B and D (Fig. 249) or between A and D, B and C whenever desired. The battery circuit is generally connected to the points A and B and the reversing circuit to C and D. When connection is direct as shown in Fig' 251 (*a*), current flows through the galvanometer in one direction but when the connection is crossed as in Fig. 251 (*b*), current flows in the reverse direction.

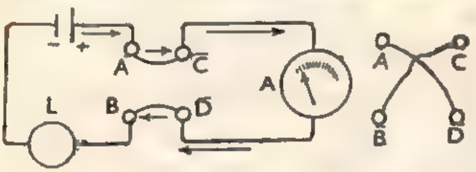


Fig. 251 (*a*) Fig. 251 (*b*)

Two-way Plug key—When a current is required to be sent through any one of the two branches in an electrical circuit, a two-way plug key is used. It consists of three isolated metal pieces A, P and C fixed rigidly to a non-conducting stand and each provided with a binding screw (Fig. 252). There are two plugs P_1 and P_2 connecting B and C to A. The common point A is joined to the main circuit and terminals of the branch circuits to points B and C. If the plug P_1 is put in, P_2 being taken out, the electrical connection is established between A and B. On the other hand if P_2 is put in, P_1 being taken out, contact is made between A and C. If, however, both the plugs are put in, B and C are simultaneously connected to A.

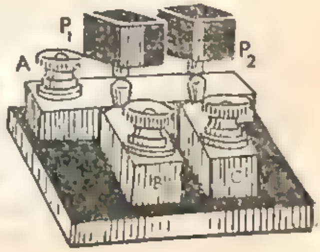


Fig. 252

Four-way Plug Key—A four-way plug key is similar in principle and construction to a two way plug key, the only difference being that instead of two metal pieces, there are four binding pieces A, B, C and D, which may be joined either jointly or severally to the common point N Fig. 253) This type of plug key is very suitable for a comparison of potential of a number of points in a circuit. The various points are connected by wires A, B, C etc. and the voltmeter or potentiometer of a galvanometer termisal to the point N.

Fig. 253

Two-way Switch and it's Operation—A two-way switch looks like an ordinary electrical switch but the lever of the switch touches a metal plate in both on and off positions. S_1 and S_2 in Fig. 254 represent two switches and the thick black U in each represents the lever of the switch operated by the key. The lever may be placed either in position 1 or 2. The thick curved line on the side is the metal plate which touches the lever in on and off positions, as shown by 1 and 2. Two such switches, one above and the other at the foot of a stair case, are fitted and are connected by wires as shown in the diagram. The mains are connected to the metal plates of the switches through an electric lamp. Note that the lamp can be operated by any one switch. This is also called a stair-case switch.

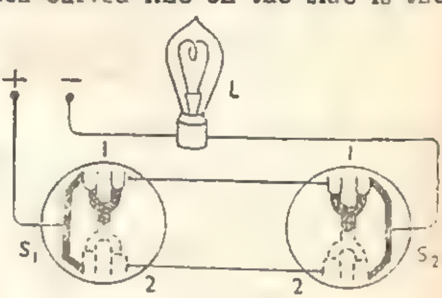


Fig. 254

Tangent Galvanometer

A tangent galvanometer consists of a circular vertical frame C over which a coil of wire is wound (Fig. 248). The terminals of the coil are connected to binding screws at the base. There is a circular graduated disc D rigidly fixed at the central part of the coil. The disc is graduated in degrees and is provided with a vertical pivot at its centre. A small magnetic needle M is suspended horizontally on the pivot so as to swing freely. A long aluminium pointer is fixed at right angles to the magnet and moves over the circular scale. Any rotation of the magnet can be read with the pointer. The circular coil with the disc is capable of rotation along a vertical axis. There are three levelling screws at the base. In some form of tangent galvanometer there are more than one coils wound on the circular frame having different resistances. In Fig. 255, the frame carries three such coils side by side having number of turns 2, 50 and 500 respectively. One end of all the coils is connected to the

left binding screw. The three other terminals are connected to separately to binding screws having number of turns marked on them. A tangent galvanometer is used to detect and measure the magnitude of current flowing through a circuit.

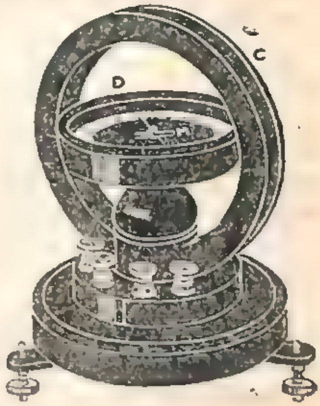


Fig. 255
Tangent Galvanometer

The three coils of such a galvanometer are often used for three different purposes, as given below—

(1) When the 2-turn coil is used in a circuit, the resistance due to it is about 0·1 ohm and the instrument then acts as a low resistance galvanometer or as an ammeter.

(2) When the 50-turn coil is used, its resistance is about 1 to 2 ohms. It is then a galvanometer for general use.

(3) When the 500-turn coil is used, whose resistance is about 200 to 250 ohms, it may serve the purpose of a fairly high resistance galvanometer or a small voltmeter. Of course for each kind of use, the scale should be properly calibrated or the reduction factor should be determined. But a tangent galvanometer is seldom used as a voltmeter.

Ohm's Law and Resistance

The current flowing through a conductor at a uniform temperature is directly proportional to the potential difference between the ends of a conductor. This is called Ohm's law. If V_a and V_b be the potentials at any two points of a conductor, V_a being higher than V_b and if a current C flows between the two points, then according to Ohm's law,

$$(V_a - V_b) \propto C \qquad \text{or} \qquad \frac{V_a - V_b}{C} = R$$

where R is a constant. This constant depends upon the volume, shape, material and temperature of the conductor. We can write the equation in the form—

$$\frac{V_a - V_b}{R} = C$$

whence we find that the larger is the constant R, the smaller is the current. Therefore it follows that the effect of this factors is to regulate the current flow in a conductor and it is, therefore, regarded as the resistance. Hence the law may also be stated thus—*The current flowing through a conductor is directly proportional to the potential difference at the ends of the conductor and inversely proportional to its resistance.* The resistance of a conductor in most cases increases with a rise of temperature.

Specific Resistance—The resistance R of a conductor is found to be proportional directly to the length l of the conductor and inversely proportional to its cross-section s. Hence from the laws of variations—

$$R \propto \frac{l}{s} \text{ or } R = \sigma \frac{l}{s}$$

σ being a constant which is called the specific resistance of the material of the conductor. From the expression of specific resistance, we see that when $l=1$ cm. and $s=1$ sq. cm., then $R=\sigma$. Therefore, specific resistance is equivalent to the resistance of a conductor of unit length and of unit cross-section, that is the resistance of a centimetre cube of the material when current flows normally to one of its faces.

Unit of Resistance—The units of resistance in both absolute and practical units are derived from Ohm's law. The electro-magnetic unit of resistance is the resistance offered by a conductor when a unit potential difference (e.m.u) causes an electromagnetic unit of current to flow. Similarly, the practical unit of resistance is the resistance of a conductor when a potential difference of 1 volt causes a current of one ampere to flow through it.

$$\text{Thus, 1 e. m. u. of resistance} = \frac{\text{1 e. m. u. of p. d.}}{\text{1 e. m. u. of current}}$$

$$\text{Similarly, 1 ohm} = \frac{\text{1 volt}}{\text{1 ampere}} = \frac{10^8 \text{ e. m. units of p. d.}}{10^{-1} \text{ e.m. unit of current}}$$

$$= 10^9 \text{ e. m. unit of resistance.}$$

$\therefore$ R ohms $= R \times 10^9$ e. m. units of resistance.

A uniform column of mercury of length 106·3 cm. and of cross-section 1 sq. mm. having a mass of 14·4521 gm. at 0°C has got a resistance of 1 ohm. Very high resistances are expressed in terms of a megohm which is 10^6 ohms.

Unit of Current—The electromagnetic unit of current is defined to be the amount of current, which flowing through an arc of length 1 cm. of a circle of radius 1 cm. produces at its centre a force of 1 dyne on a unit magnet pole. The practical unit of current is an *ampere*, which is one-tenth of the corresponding electromagnetic unit.

Resistance Coils and Boxes

A resistance box contains a number of coils of fixed resistances connected in series. The wire with which the coils are wound, is double silk-covered and is made of some alloys *e.g.*, manganin, german silver, constantan, etc., which have high specific resistance and small temperature coefficient. The wire of each coil is first folded so as to be doubled up and is then wound on a small wooden cylinder fixed rigidly within the box. The terminals of each resistance coil are soldered to two brass pieces AB (Fig. 256) having an air gap between them. The value of each resistance coil is marked. The

air gap may be closed tightly by means of a metal plug P whenever necessary.

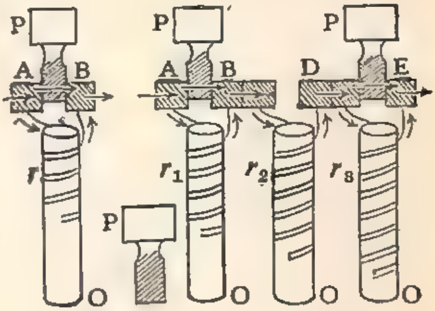


Fig. 256 Fig. 257

To understand the action of a resistance coil when put into an electrical circuit, suppose that the two metal pieces A and B (Fig. 257) are connected to a circuit carrying current, and let the current flow in the direction of the arrow head. *When the plug is tightly fitted*, the current on entering A is divided into two branches: one part going through the body of the plug to B and the other part, although a very minute fraction, travelling through the resistance r. Hence the resistance of the body of the plug and that of coil are connected in parallel. The resistance of the plug is practically zero, hence the equivalent resistance R of the combination is according to equation,

$$R=\frac{r\times 0}{r+0}=0$$

Hence, *when the plug is fitted, the corresponding resistance coil is ineffective.*

Again, when the plug key is taken out, and air gap is formed having an infinite resistance. The entire current flows through the resistance coil r, and the equivalent resistance R is given by the relation,—

$$\frac{1}{R}=\frac{1}{\infty}+\frac{1}{r} \quad \text{or,} \quad R=r$$

Hence, *when the plug is taken out, the corresponding resistance of the coil is introduced into the circuit.*

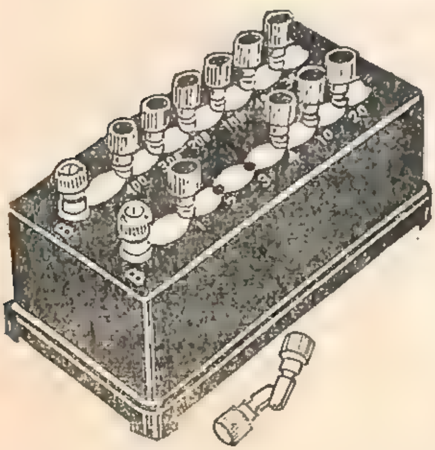


Fig. 258

In practice a number of resistance coils of different values are joined in series as in Fig. 258. Two ends of the series are provided with two binding screws through which current enters and goes out. When any such coil is required to be put into the circuit, the corresponding plug key is taken out so that current then circulates through the coil. A resistance box of smaller type having a maximum resistance of 400 ohms is shown in Fig. 258. Resistance boxes of higher ranges are also available. The current bearing capacity of the coils, specially those

for higher resistances, is small, being about a tenth of an ampere. Care must be taken not to send a current much more than the safe limit assigned to a particular resistance box. If a large current passes accidentally through any coil the heat produced may melt the paraffin coating of the coil or even burn out the coil causing a permanent damage to it.

Slide Rheostat

It consists of a long uniform wire wound over a non-conducting cylinder. The two terminals of the wire are connected to the binding screws SS (Fig. 259). A metal rod, over which a jockey J can slide, is rigidly fixed above the coil. A spring attached to the jockey makes a metallic contact with the rod and the part of the coil immediately below it. A binding screw B is fitted at one end of the rod. The instrument is provided with a suitable stand. The terminals of a circuit are connected to the point B and any one point S. Now the position of the jockey determines the portion of the coil introduced into the circuit. By altering the position of the jockey, different lengths of the wire are inserted into the circuit and hence current is regulated by altering the effective resistance.

Fig. 259

Fig. 260 is a diagram showing the manner of connecting a rheostat in an electrical circuit. One terminal of a cell E is connected by a wire to the binding screw S_1 of the rheostat. The other terminal of the cell is connected to a galvanometer G. The other binding screw of the galvanometer is joined by a wire to the point B of the rheostat.

As shown in the figure the current from the cell enters through the end S_1 of the rheostat, circulates through the resistance coil and leaves the coil at D at the point of contact of the jockey. Then it passes through the rod and circulating through the galvanometer coil goes back to the cell. Hence the effective portion of the rheostat introduced into the circuit is the length of the resistance wire between the points S_1 and D. The part DS_2 remains unused. Hence it is evident that as the point of contact of the jockey is moved to the right so as to increase the length of the coil, the resistance is increased and the deflection of the galvanometer gets smaller.

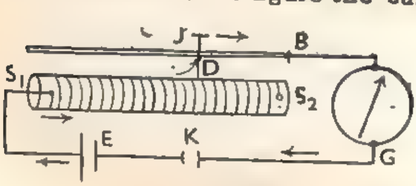


Fig. 260

Combination of Resistances—For practical purposes it becomes necessary to combine several resistances in a circuit. This can be done practically in *two* ways :—

When several resistances are connected one after the other in such

a manner that the current is the same in any one of them, they are connected *in series* (Fig. 261). If r_1 r_2, r_3 etc. be the resistances

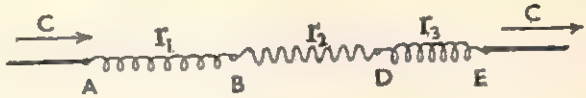


Fig. 261

connected in series, the equivalent resistance R is given by the relation,

$$R = r_1 + r_2 + r_3 \dots\dots\dots$$

When several resistances are connected in such a way that one terminal of each is joined to one point and other terminal to another point, the combination is said to be *in parallel* (Fig. 262). In this case current enters the circuit through one joint, divides in all the branches and finally goes out through the other joint. If r_1, r_2, r_3 etc. be resistances, all connected in parallel, the equivalent resistance R is given by the relation,

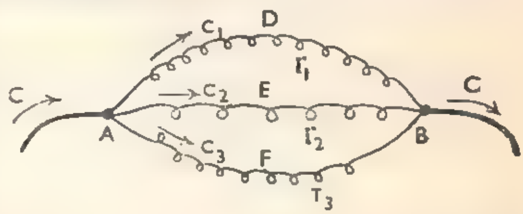


Fig. 262

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \dots\dots$$

Date—

Experiment 139

To Verify Ohm's Law with a Tangent Galvanometer

Theory—Ohm's law states that current C flowing through a conductor is directly proportional to the potential difference E and inversely proportional to the resistance R. In both the systems of units, E = CR.

If the e.m.f. of the circuit is constant, the current may be changed by altering the resistance of any part of the circuit. In each case the product of the current and the total resistance of the circuit is constant and is equal to the e.m.f. of the circuit. The current C passing through a properly adjusted galvanometer is equal to K $\tan\theta$, where K is a constant of the tangent galvanometer. If S is the total resistance of the circuit,

$$\text{then}\quad E = CS = 3K \tan\theta \quad \text{or,}\quad S \tan\theta = E/K = \text{constant.}$$

Apparatus—A tangent galvanometer, a resistance box, an accumulator, a commutator and connecting wires.

Procedure—Connect two terminals of a storage cell to the two binding screws of a commutator by two pieces of wires. See that the contact plugs of the commutator are off while making such connections. Now connect the tangent galvanometer *in series* with a resistance box and join the free terminals of the combination with two other binding screws of the commutator. The representative diagram is shown in Fig. 263 while the actual manner of connection is represented in Fig. 264. The resistance box may be directly connected either with the cell or with the galvanometer, since it does not alter the nature of the circuit. (The student is required to draw only the representative diagram in the Fair Note Book.)

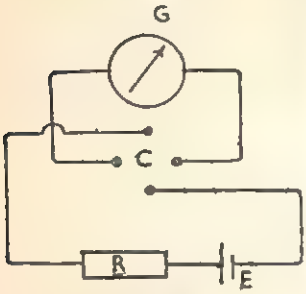


Fig. 263

Place a spirit level at the central part of the glass cover of the dial of the tangent galvanometer and level the instrument with the base screws so that the magnet is suspended freely. To test the free suspension of the needle, bring a bar magnet at some distance from the needle to get a fair deflection. On taking away the magnet, the needle would oscillate almost equally on two sides of its position of rest. Now rotate the coil about the vertical axis until the pointer attached to the needle reads 0° – 0° on both sides of the circular graduated scale. The plane of the coil is now parallel to the magnetic meridian.

Put a resistance of a few hundred ohms in the resistance box by taking out the corresponding plug and close the circuit. When the deflection of the galvanometer becomes steady, take the reading of both the pointers. Then decrease the resistance in the resistance box by some amount and again take the reading of the pointer. In this way, record a number of readings with values of resistance and corresponding deflection of the galvanometer needle. Tabulate the readings as shown in the adjoining table. Get the values of cotangent of all the mean values of the angles of deflection from a book of tables.

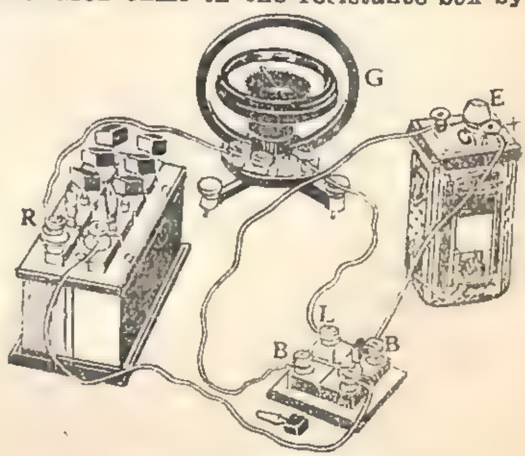


Fig. 264—Actual connection

Now plot a graph with the value of cot θ as abscissa and the corresponding resistance inserted in the resistance box as ordinate

(Fig. 265). The graph is a straight line as proved below. Let E be the e.m.f. of the cell, r the internal resistance of the cell, G the

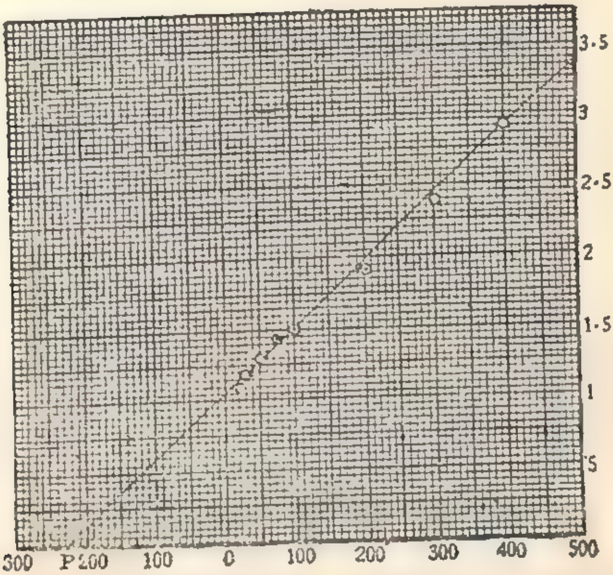


Fig. 265—Verification of Ohm's law

resistance of the galvanometer and R the resistance put in the resistance box. Then the current C flowing through the galvanometer is given by

$$C=\frac{E}{r+G+R}=K\tan\theta, \text{ or } \frac{E}{K}\cot\theta=r+G+R$$

$$\therefore \quad \cot\theta=\frac{K}{E}R+\frac{K}{E}(r+G)$$

Since E/K is a constant and $r+G$ is another constant for a given cell and galvanometer, the relation between $\cot\theta$ and R represents a form of the equation $y=mx+b$ which is a straight line. The straight line meets the resistance axis at a certain point P for some negative value of resistance R. Measure this negative value, and call it $-p$. For this point $\cot\theta=0$, and since K/E is not zero,

$$r+G-p=0 \text{ whence } r+G=p$$

If Ohm's law is valid, $(r+G+R)\tan\theta=(p+R)\tan\theta=E/K$. The value of $(r+G+R)\tan\theta$ is shown at the last column of the table. Since the product is constant within the limits of the experimental error, the law is verified.

Result—

No. of Readings	Resistance of the box in ohms	Value of $p=r+G$ measured from graph	Mean Deflection θ degrees	Cot θ	Tan θ	$(r+G+R) \times \tan\theta$
1	500	225	16·5	3·376	0·299	214·6
2	400	,,	19	2·9	0·344	215·6
3	300	,,	22·5	2·41	0·414	217·1
4	200	,,	27	1·96	0·51	216·4
5	100	,,	33·5	1·51	0·66	214·8
6	80	,,	35	1·43	0·7	213·5
7	50	,,	38	1·28	0·78	214·5
8	30	,,	40	1·19	0·839	213·9
9	20	,,	41	1·15	0·862	212·9

Discussions—The values of θ round about 45° should be recorded, since the relative accuracy in measuring the current for a deflection near about 45° is high. The lower is the resistance of the galvanometer, the more accurate is the graph and hence the better is the constancy of the product.

ORAL QUESTIONS

What is Ohm's law? How are you going to verify Ohm's law by this experiment? What is the function of the Tangent Galvanometer here? What is the construction of a tangent galvanometer? Why do you set the galvanometer at 0°—0° at the start? How do you find the resistance of the galvanometer and the battery? Is it necessary that an accumulator should be used? What is the harm if a Leclanche's cell be substituted for the accumulator? Is it possible to verify the law with a sine galvanometer?

Moving coil Galvanometer

To detect and measure current of the order of a millionth of an ampere or even less, a moving coil galvanometer is used. The current to be measured is led through a small rectangular coil containing many turns of fine insulated copper wire (within the casing of the galvanometer), the terminals of which are connected to the binding screws BB (Fig. 266) The coil is pivoted and is capable of rotating in a small space between the pole pieces of a horse-shoe magnet. When current passes through the coil, a couple tending to rotate the coil is set up due to the action of magnetic field on current. The stronger is the current, the larger is the effect of the couple. Two hair springs control the motion of the coil and keeps it always at a fixed position when no current is passing. The coil is provided with a metallic pointer moving over a graduated

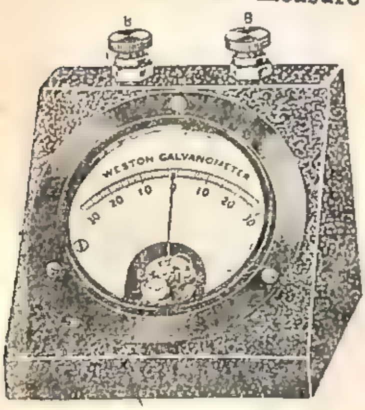


Fig. 266—Moving Coil Galvanometer

dial at the front of the instrument. The scale is graduated both ways, the centre being zero. The pointer is against the zero mark when no current passes. The deflection of the pointer is an indication of the current passing through the coil and the amount of deflection is proportional to the strength of the current. In this class of instrument a deflection of one scale division corresponds to the order of a millionth of an ampere. The value of one scale division in ampere is indicated on the instrument or it can be measured also. The value of the current for a deflection of n scale divisions is then n times that value. (For details vide Basu & Chatterjee's Intermediate Physics, Electricity, Chapter XIII.)

Ammetres and Voltmeters

These are modified forms of suspended coil galvanometers. An ammeter is designed to read the current of a circuit directly in ampere or any fraction of it, while a voltmeter reads the difference of potentials between any two points of circuit in volts. A suspended coil pattern of ammeter is shown in Fig. 267. The construction and principle of an ammeter are similar to those of a suspended coil galvanometer, only with a difference that the coil is provided with a *shunt of suitable resistance* depending upon the range of the current to be measured. When a current is passed through the instrument, only a small fraction of it passes through the coil deflecting

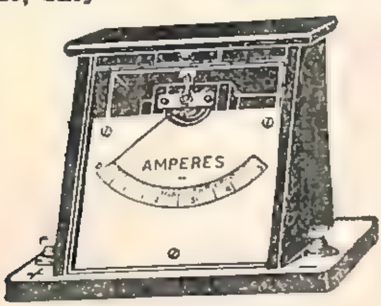


Fig. 267—Ammeter

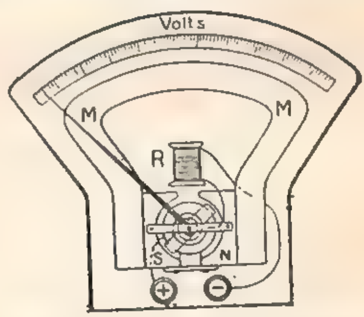


Fig. 268—moving Coil Voltmeter

the pointer while the major part finds a separate passage through the shunt resistance. The scale is calibrated so as to record the total current. The scale is graduated in one direction only, so that it is necessary to pass the current through the instrument always in one direction to get any reading. For this reason one binding screw is marked + and the other − to indicate high and low potential terminals. An ammeter is always to be put *in series* in the circuit to measure a current. Such a type of ammeter is to be used in direct current circuit only. It is ineffective in alternating current circuit. It is to be carefully remembered that if by mistake an ammeter is connected *in parallel to a circuit or even across a battery of cells or mains without adequate resistance*, the ammeter coil would burn-out causing permanent damage to it.

A suspended coil voltmeter is identical in construction and action except that there is a resistance of a suitable value connected in

series with the coil depending upon the range of the voltage to be measured. Fig. 268 illustrates the principle of a voltmeter in which M represents the magnet and NS the pole-pieces. The coil works within the cylindrical gap and is provided with a pointer moving over the scale. R is the high resistance in series with the coil. The scale is graduated in volts. It is, therefore, necessary that current should be passed through the coil in one direction. For this reason binding screws are properly marked. The leads from the voltmeter are connected to two points the difference of potentials of which is to be measured. Such a type of voltmeter is to be used only in direct current circuit. It is repeated for a careful remembrance of the students that an *ammeter is to be connected in series* in a circuit to measure its current and *a voltmeter is parallel with the part of the circuit* whose potential difference is to be measured. Further such instruments must never be used in a circuit, where the current or the voltage to be measured, exceeds the limit shown by the dial of the instrument.

Date—

Experiment 140

To Verify Ohm's law with a Voltmeter and an Ammeter

Theory—If V be the difference of potentials at the terminals of a conductor and C the current flowing through it, then so long as its temperature is fairly uniform,—

V/C = a constant = resistance of the conductor.

Apparatus—A high resistance voltmeter (10000 ohm per volt), an ammeter, a rheostat, a coil of wire, a battery of cells, a key and connecting wires.

Procedure—The terminals of a battery of cells of about 6 volts are connected by wire through an ammeter, a standard resistance of about 5 ohms, a key and a rheostat all in series. The high potential side of the battery is connected to the binding screw of the ammeter marked + (Fig. 269). The voltmeter V is connected in parallel across the standard resistance CD with its high potential end at the + screw.

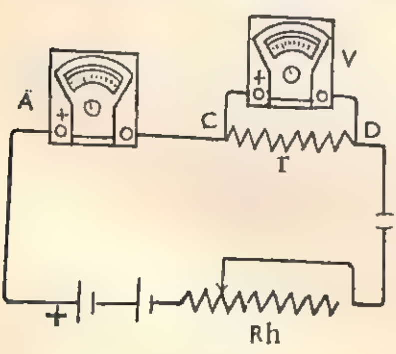


Fig. 269

The ammeter should have the full scale graduation of 1 ampere and subdivided into 100 parts. The voltmeter should have a full scale deflection of 5 volts and may have 100 divisions of the scale. The rheostat is a slide wire having a maximum resistance of about 60 ohms.

The rheostat is so adjusted as to have maximum resistance, and the readings of the voltmeter and ammeter are recorded. The resistance of the rheostat is brought down by almost even steps and the readings of the voltmeter and ammeter are taken for each step. Since for any particular set, the

voltmeter reading divided by the ammeter reading gives the resistance of the coil in ohms, the ratio given in the last column should be very nearly constant.*

Results—

No. of observation	Voltmeter reading V volts	Ammeter of reading C amps.	Ratio of V/C
1	1·00	0·20	5·0
2	1·60	0·32	5·0
3	2·50	0·51	5·0
4	3·25	0·62	5·1
5	4·70	0·88	5·1

Discussions—It is to be noted that ratio is slightly higher for a large current, which shows that resistance increases with temperature. The voltmeter and the ammeter for this experiment should be graduated to read a very small fraction of the voltage and current. It is not possible to measure a resistance correct to more than one place of decimals by the voltmeter and ammeter method, simply because dial readings for those instruments cannot be taken without a possible error of 1 to 5 per cent.

Ohm's law can be very accurately verified if the potential difference be measured with a potentiometer with a standard cell and current be measured with a copper voltmeter in the circuit. This way of verifying the law is even far superior to the conventional tangent galvanometer method from the point of accuracy.

Date— EXPERIMENT 141

To Measure the Resistance of a Voltaic Cell

Theory—If E volts represent the reading of a higher resistance voltmeter when connected to the terminals of a cell and E_1 volts the reading of the voltmeter when a resistance of R ohms and an ammeter are connected to the coil

$$\text{then} \quad r = \frac{E - E_1}{C}$$

where r = the internal resistance of the cell and C = the current in amperes as recorded by the ammeter.

*There is apparently some misconception that Ohm's Law cannot be verified by a combination of voltmeter and ammeter. The argument given in favour is that since the readings of the voltmeter and ammeter depend upon the application of Ohm's Law, how can such apparatus be used to verify the law in a subsidiary circuit. But the fact is that a high resistance voltmeter takes in *so little quantity* of current from the testing circuit that it can be safely said that current distribution of the circuit does not appreciably change. Further the ammeter has so *very small resistance*, that there is no appreciable potential drop across its terminals. In the circumtances, the two instruments almost satisfy the ideal conditions and the verification of Ohm's law is, within the limits of experimental errors, as accurate as with a tangent galvanometer.

Apparatus—A Daniell's cell, a high resistance D. C voltmeter graduated in ·02 volt, a D.C. ammeter graduated in 0·2 ampere, rheostat and a plug key.

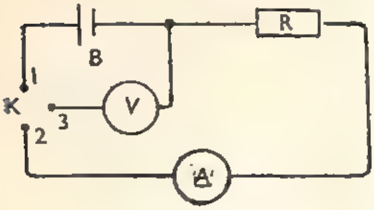


Fig. 270

Procedure—Make an electrical circuit as shown in Fig. 270. Connect the positive end of the voltmeter to the positive pole of the cell B. Connect the negative pole of the cell to the common point of a two-way plug key. Connect also the other terminal of the voltmeter to another point (no. 3) of the plug key. Connect a rheostat and an ammeter (in proper direction) in series with the cell through the third point of the plug key.

Place the plug key as to make a contact between points 1 and 3, the point 2 remaining open The voltmeter record gives E. Put some resistance in the rheostat and put a second plug key to make a contact between the points 1 and 2. Now read both the ammeter and volt-meter. Thus C and E_1 are known. Take a number of values of E_1 and C each time by altering the rheostat resistance. Finally, tabulate the observations as shown below. Hence calculate r from each set and find the mean value.

Results—

No. of readings	readings E_1 volts	readings E_1 volts	readings C amps.	$\frac{E-E_1}{C}=r$ ohm	Mean r ohm.
1	1 08	1·00	·2	·4	
2	,,	...	...	...	
3	,,	1 02	·15	.	·38
4	,,	...	...	·38	
5	,,	1·01	...	·38	

Discussions—The resistance of the voltmeter should be very high as compared to the external resistance R Both the voltmeter and ammeter should have fine graduations to read a small change of voltage and current.

ORAL QUESTIONS

What do you mean by internal resistance of a cell? What are the factors governing the internal resistance? What type of cells you would choose for electrical experiments—a cell of large or small internal resistance? Why are constant e.m.f. cells provided with large internal resistance?

Principle of Wheatstone's Bridge

Ordinary electrical resistances are most generally measured by a method of comparison depending upon the principle of Wheatstone's Bridge, as described below. Four resistances of values r_1, r_2, r_3 and r_4 are connected to form four arms of a quadrilateral having junctions

at A, B, C, and D (Fig. 271). The poles of a cell S are connected to points A and D through a plug key K and the terminals of a galvanometer G are connected to points B and C through another key K_2. Let the larger line of the figure representing the cell S be the positive terminal. When the keys are closed the current on arriving at A, will be divided into two parts one passing through r_1 and r_2 back to the cell. The other parts passes through r_3 and r_4 back to the cell. Some current also passes through the galvanometer and the direction of such current will depend upon the potentials of B and C.

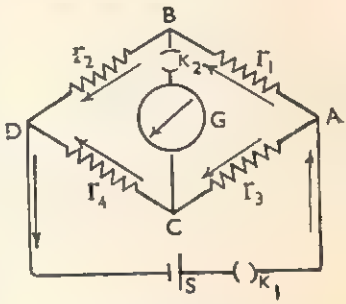


Fig. 271

If now the value of resistance in one or more arms be changed, the current in any branch changes. By repeated trials of adjusting the resistances a condition may be so attained that no current flows through the galvanometer, while the circuit is complete. This would be evident from the fact that there would be no deflection in the galvanometer. Experiments depending upon the condition of no deflection of the galvanometer are called *null methods*.

While the circuit is complete, let the potentials of the points A, B, C and D be V_A V_B V_C and V_D respectively. For no deflection adjustment $V_B = V_C$. Let C_1 and C_2 be the current passing through r_1 and r_3 respectively. Then since no current is passing between B and C, current passing through r_1 is the same as that through r_2. Also the current passing through r_3 is equal to that passing through r_4. Then, from Ohm's law,—

$$C_1 = \frac{V_A - V_B}{r_1} = \frac{V_B - V_D}{r_2}$$

and $$C_2 = \frac{V_A - V_C}{r_3} = \frac{V_C - V_D}{r_4}$$

Since $V_B = V_C$, then by division

$$\frac{C_1}{C_2} = \frac{r_3}{r_1} = \frac{r_4}{r_2} \quad \text{or,} \quad \frac{r_1}{r_2} = \frac{r_3}{r_4}$$

Metre Bridge—It consists of a rectangular wooden board AB

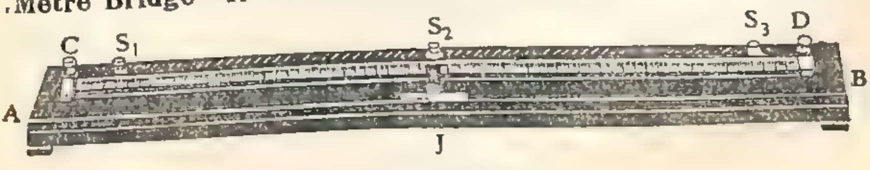


Fig. 272—Metre Bridge

over which a straight uniform wire, one metre in length, is stretched by the side of a metre scale (Fig. 272). The ends of the wire are soldered to two copper strips fixed to the body of the board. The

two strips have got two binding screws C and D. Another long copper strip, having three binding screws S_1, S_2 and S_3 are fixed on the board so as not to touch copper strips on either side leaving two gaps on either sides. There is a slider J having a sharp metal edge resting on the wire and is capable of moving through a groove parallel to the length of the wire. It is called the jockey J which is also provided with a binding screw.

In some other form of metre bridge, there are four air gaps between the copper strips (Fig. 273) suitable for other experiments.

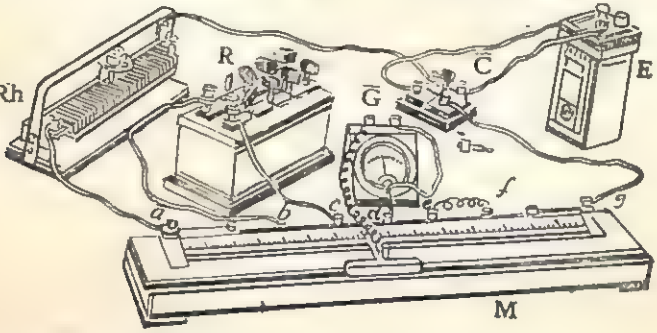


Fig. 273—Actual arrangement of apparatus

But it may also be used for ordinary resistance measurements by closing two extra air gaps by copper connecting pieces.

To use a metre bridge for measuring a resistance, the poles of a cell are connected to the screws C and D (Fig. 272) and the terminals of a galvanometer to the screw S_2 and the jockey. A known resistance is connected between the gap CS_1 and the known resistance at S_3D. The copper strips have got negligible resistance. We may say that the point A of Fig. 271 corresponds to the copper strip at the right end side of Fig. 272, point B to the long copper strip, point D to the left side strip and point C to the point where jockey touches the wire. Then the resistance r_1 corresponds to some unknown resistance (say, X) inserted within the gap S_2D, r_2 to some known resistance of the resistance box (say, R) r_3 to the resistance of the wire to the right portion of the jockey and r_4 that to the left portion of the jockey. If the zero of the scale begins from the left and if for a position of the jockey at l cm., the galvanometer shows no deflection, it is evident from the theory of Wheatstone's Bridge that,

$$\frac{R}{X}=\frac{\text{resistance of the length } l \text{ cm. of the wire}}{\text{resistance of the length } (100-l) \text{ cm. of the wire}}$$

The wire being uniform, the resistance per unit length of the wire is the same. Let it be ρ.

$$\text{Then,}\quad \frac{R}{X}=\frac{l\rho}{(100-l)\rho}=\frac{l}{100-l}$$

$$\text{Whence, } X=R\,\frac{100-l}{l}\text{ ohms.}$$

Thus knowing R and the null point on the bridge wire, we can find the unknown resistance with a metre bridge.

Date— EXPERIMENT 142

To Find the Resistance of a Wire by Metre Bridge

Theory—If a null point is obtained at a distance l cm. of the jockey with a known resistance R in the left gap and an unknown resistance X at the right gap of a metre bridge, then

$$X = R\,\frac{100-l}{l}\text{ ohms.}$$

Apparatus—A metre bridge, a galvanometer, a resistance box, a rheostat, commutator, cell and resistance coil.

Procedure—Connect the poles of a cell E by wires to the binding screws a and g of a metre bridge through an adjustable rheostat Rh and a commutator C (Fig. 273). Join with a piece of wire one terminal of the suspended coil galvanometer G to the binding screw d and the other to the movable jockey. Connect a resistance box R at one air gap at points b and c and a coil of wire under examination at another air gap at points c and f. Before connection the terminals of each wire should be cleaned with sand paper and connections to the binding screws should be tight to ensure a good contact. A representative diagram is given in Fig. 274 while the actual method of connection is shown in Fig. 273. (Students are required to draw a representative diagram of this arrangement as shown in Fig. 274).

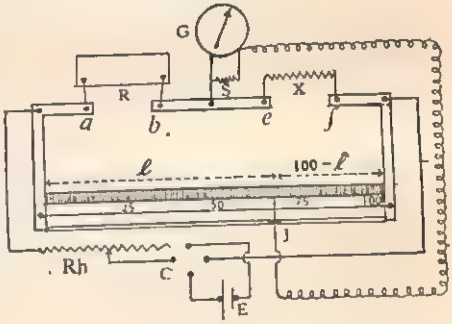


Fig. 274—Representative Digram

Introduce about half the resistance of the rheostat and put a resistance of a few ohms (say, R) in the resistance box. Close the commutator and take the jockey to one extreme end of the wire and press it to make a contact with the wire. Note the deflection of the galvanometer. Then take jockey to the other end, press it and note the deflection. If this deflection be in opposite direction, the connections are correct.

Now slide the jockey over the wire to a suitable position to get the null point. If this point happens to lie near the end of the wire, alter the resistance of the box slightly and observe the null point. In this way, by repeated trials bring the null point near the middle part of the wire. Because at this part resistance is determined with greatest accuracy. Take two readings of the null point for the same resistance of the box, first on gradually sliding the jockey from left to right and second by moving the jockey from right to left direction. Now reverse the direction of the current and take two readings for the null point in a similar way. The mean of these

four readings represents the null point corresponding to a particular resistance of the box. Change the resistance of the box slightly and in a similar way find another set of four null points. Interchange the resistances R and X in the two gaps and record similar sets of readings. When the resistances are reversed, then in the main equation X should be replaced by R and R by X.

Results—

No. of obs.	Readings of null points		Mean Reading l cm.	Known resistance R ohms	Unknown Resistance $X = R \times \frac{100-l}{l}$ ohms
	Direct cm.	Reversed cm.			
1	56·4	56·5	56·45	5	3·82
2	...	...		...	
3	48·8	48·8	48·8	4	3·82
4		...	...	...	...

Discussions—The mean value of the resistances as experimentally determined is 3'82 ohms. The null points should be obtained at the middle part of the bridge wire to minimise the percentage of error in the determination of resistance. The eliminate uncertainties of thermo-electric effects the null point is found both for direct and reversed currents. A metre bridge is suitable for measurement of resistance of a moderate range, neither too high not too low.

Oral Questions

What is a Wheatstone's bridge? What is the principle upon which a Wheatstone's bridge works? What is called the null method? What is the function of the jockey? Why is a metre bridge provided with a uniform wire? Why is the wire one metre long? Why is the null point to be sought for at the middle part of the wire? Is it suitable for measuring any magnitude of resistance? What is the practical unit of resistance and what is its magnitude? How is it connected with the C. G. S. unit of resistance?

End Corrections—That the ratio of the two resistances put in the two gaps of the metre bridge is equal to the ratio of the two segments of the slide wire is derived by assuming that the resistances of the copper strips and those of various junctions are *very negligible* as compared to the resistance to be measured and that the two ends of the slide wire are exactly coincident with the zero and hundred centimetre marks of the attached scale.

But due to the fact that there is some small resistance associated with each copper strip, various junctions of metals and at the soldering contact, as also the metre scale not exactly coinciding with the wire end to end, there are two very small resistances coming in on two sides of the null point. Let these two resistances be p and q respectively, These are called the terminal resistances. If these resistances be equivalent to a and b centimetre lengths of the bridge wire, then these equivalent lengths are called *end-corrections.*

Date—

EXPERIMENT 143

To measure the Resistance per unit length of the Metre Bridge Wire by Carey Foster's Method

Theory—With electrical connections as shown in the Fig. 275, if P and Q be nearly equal resistances put in the two inner gaps of a metre bridge, R and S two other resistances in the end gaps so that a null point is obtained at a distance l on the bridge wire, then

$$\frac{P}{Q}=\frac{S+l\rho+a}{R+(100-l)\rho+b}$$

where ρ = resistance per unit length of the metre bridge wire, a and b are any stray resistances at various junctions on either half of the metre bridge wire. On reversing R and S and getting another null point at l'. We get,

$$\frac{P}{Q}=\frac{R+l'\rho+a}{S+(100-l')\rho+b}$$

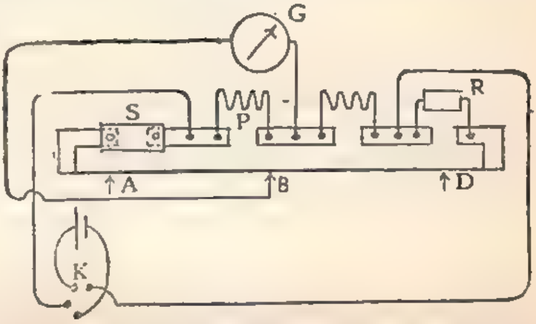


Fig. 275

From the two equations,

$$\frac{S+l\rho+a}{R+(100-l)\rho+b}=\frac{R+l'\rho+a}{S+(100-l')\rho+b}$$

Hence by the process of componendo-dividendo and simplification,

$$R-S=\rho\ (l'-l)$$

Apparatus—Metre bridge, two equal lengths of similar wire, copper connectors, fractional resistance box, suspended coil galvanometer, connecting wires, cell, commutator and rheostat.

Procedure—Connect with wires the terminals of a cell through a commutator and rheostat to the binding screws of the metre bridge as shown in the diagram. Connect two equal lengths of wires (3 to 4 ohms resistance) of resistances P and Q to the gaps. Also connect a copper connector and a fractional resistance box at the end gaps as shown. Connect the terminals of a galvanometer between the middle binding screw and the jockey.

Take out certain fractional resistance of the box and find a null point on the bridge wire. If the null point be near the middle part, take out a higher fractional resistance to shift the null point towards the end. Select such a resistance that the null point is obtained as near to the end as possible. Note the null points for direct and reverse currents.

Now interchange the copper connector and the resistance box without altering the resistance of the box. Take again two null points one for direct current and the other for reversed.

Take two or three sets of observations *slightly* altering the resistance of the box and tabulate the observations in the following way.

Results—

No. of Readings.	Resistances		Null points cm.			$\rho\frac{ohm}{cm.}$
	R ohm	R ohm	Current Direct	Current Reverse	Mean	
	·6	0	24·8	24·8	24·8	
1	0	·6	74·7	74·8	74·75	·012
	...	...	...	...	...	
...	...	...	...	...	...	
...	1.1	0	4·1	4·2	4·15	
4	0	1·1	95·8	95·9	95·85	·012

Discussions—The electrical contacts between various resistances must be very good, as otherwise faulty readings would be obtained. Null points should be near the ends of the wire so as to include largest possible portion of the wire under investigation.

ORAL QUESTIONS

What is the principle adopted in Carey Foster's method of connection? Why do you use a fractional resistance box? Why are two nearly equal resistances used as ratio arms? What is the end correction? How do you eliminate the end correction?

Electrolysis

When electricity is passed through a solution containing a salt solution or an acid, a sort of molecular decomposition takes place which is called the *ionic dissociation* Each dissociated part containing an atom or a group at atoms is found to be electrically charged and is called an *ion*. The process of decomposition of a compound by electric current is called electrolysis and the vessel in which electrolysis is carried out is called a *voltameter*. The current is led into the solution by a conductor which is called the *anode* and the other conductor by which the current leaves the solution is called the *cathode*. The ions, which appear at the anode or positively charged electrode must be charged negatively. For this reason they are said to be *electro-negative* in character. Similarly, ions appearing at the cathode are electro-positive in nature. All metallic radicals as also hydrogen are electro-positive in character. For further study vide Basu & Chatterjee's Intermediate Physics Vol. II, Electricity).

Faraday's Laws of Electrolysis

As a result of investigation on the behaviour of solutions to electrolysis, Faraday derived the *two* following laws of electrolysis :

(*i*) *The amount of an ion liberated from an electrolyte at each electrode is proportional to the quantity of electricity which passes through it.*

(*ii*) *If the same quantity of electricity passes through several electrolytes, the amounts of ions liberated at different electrodes are proportional to their chemical equivalents.*

To explain the laws, suppose that Q amount of electrical charge flowing in t seconds deposits a quantity W of an ion from an electrolyte, then from the first law, $W \propto Q$. But the quantity of charge Q is the product of the current C produced and the time t for which the current flows. Therefore $Q = Ct$.

$$\text{or,}\quad W \propto Ct \qquad\qquad \text{or,}\quad W = ZCt$$

where Z is a constant depending on the nature of ion deposited. If $C = 1$ ampere and $t = 1$ second then Z is numerically equal to W and is called the electro-chemical equivalent of that ion. Thus electro-chemical equivalent of an element is the amount of ion of that element liberated when 1 ampere of current is sent through the electrolyte for 1 second or when 1 coulomb of charge passes through the electrolyte.

If the same amount of charge flowing through a number of electrolytes liberates W_1, W_2, W_3 etc. grams of various elements having chemical equivalents m_1 m_2, m_3 etc. then according to the second law,—

$$W_1 : W_2 : W_3 : \cdots\cdots = m_1 : m_2 : m_3 : \cdots\cdots$$

The chemical equivalent of an element is the mass of the element which would combine with or replace 1·008 gm. of hydrogen. For an element, its chemical equivalent is numerically equal to its atomic weight divided by valency. For silver the chemical equivalent is 108, for oxygen 8, etc., taking the atomic weight of hydrogen to be 1·008.

Date— EXPERIMENT 144

To determine Electro-chemical Equivalent of Hydrogen with a Hoffman's Voltameter

Theory—If m gm. of hydrogen is liberated from acidulated water due to the passage of C amperes of current for a period of t seconds, and if Z be the electro-chemical equivalent of hydrogen, then

$$Z = \frac{m}{c \times t}$$

In fact the mass of hydrogen liberated is calculated from its volume collected in a graduated cylinder at a known temperature and pressure. The nature of calculation is shown for simplicity in the result portion.

Apparatus—A Hoffman's voltameter, a galvanometer, a key, a battery of cells.

A Hoffman's voltameter consists of three interconnected vertical tubes of which the two side tubes are graduated in cubic centimetres

and are provided with gas tight stop-cocks (Fig. 276). The middle one ends in a funnel. Two platinum electrodes are sealed into the outer tubes from the bottom.

Method—Fit up the Hoffman's voltameter in the vertical position with suitable clamps. Take a beaker nearly filled with water and add a few drops of sulphuric acid. The purpose of acidulating water is to make it electrically conducting, since pure water is almost a non-conductor of electricity. Open the two taps of the side tubes and pour acidulated water into the funnel of the middle tube until water nearly overflows.

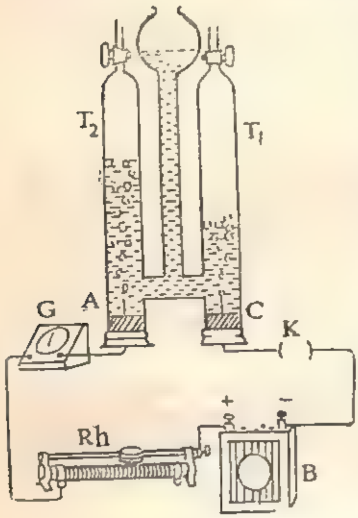


Fig. 276

Now connect the electrodes of the voltameter through a key, a battery of cells, a rheostat and an ammeter as shown in the diagram. Close the stop-cocks and switch on the current. Bubbles of gas are observed to go up and accumulate at the tops of the tubes. If the bubblings are too rapid increase the resistance of the rheostat until bubblings are moderate. When the water levels of the side tubes come down to occupy the graduated portion, stop the electric current when bubbling at once ceases. Read the levels of water in both the tubes and wait for some time to check the readings. If the readings do not alter, then the stopcocks are gas-tight and there is no leakage from the tube.

Read the water levels of the tubes accurately. If the water levels are too down inside the tubes, the stop-clocks may be partially opened when a portion of the gas would escape and the levels would come up to convenient heights. Switch on the current and simultaneously start the stop-clock. Read the current as recorded in the ammeter. Gases are found to be collected in the tubes at different rates. The gas which is more collected is hydrogen evolving at the cathode. Make the current flow until the level of water within the hydrogen tube comes near the bottom but *within the graduated part*. Switch off the current and at once stop the clock. Read the time on the clock and the level of water in the hydrogen tube. Record the difference in water levels of the middle and hydrogen tube.

Insert a thermometer through the funnel tube into water and read the temperature of water. Finally read a Fortin's barometer.

Results—

Current recorded by ammeter = c amp.
Time for which current flows and hydrogen is collected = t sec.
Volume of hydrogen collected = V c.c.
Difference in water levels = h cm.

Temperature of water $=\theta^{\circ}$C.

Barometric pressure $=$ P cm. of mercury.

Since hydrogen is collected in a closed tube containing water, there is saturated water vapour along with the gas. So pressure in the tube $=$ pressure of hydrogen $+$ pressure of water vapour. Find out from a Table the saturated pressure of water vapour at θ°C and call it p_1. Let the pressure due to hydrogen be p,

$$\text{Then.}\quad P+\frac{h}{13\cdot6}=p+p_1 \quad\text{whence}\quad p=P+\frac{h}{13\cdot6}-p_1$$

If V_0 be the volume of hydrogen at N.T.P. then from gas laws,—

$$\frac{V_0\times76}{273}=\frac{V\times p}{273+\theta}\quad\text{whence}\quad V_0=\frac{V\times p\times273}{(273+\theta)\times76}$$

Now 1 c.c. of hydrogen at N.T.P. weighs 00009 gm.

$\therefore$ V_0 c.c. " " " $V_0\times{}^{\cdot}00009$ gm.

$$m=\frac{V\times p\times273\times{}^{\cdot}00009}{(273+\theta)\times76}\text{ gm,}$$

$$\text{Thus,}\quad Z=\frac{m}{c\times t}=\frac{V\times p\times273\times{}^{\cdot}00009}{(273+\theta)\times76\times ct}\text{ gm /coulomb.}$$

Discussions—The voltage of the battery should be sufficient to electrolyse acidulated water. For a satisfactory electrolysis, it should be 6 to 10 volts. The current strength should be so adjusted that the period of collection of hydrogen be 10 to 15 minutes for accuracy of result. The stop-clocks should be thoroughly guarded against any leakage. The ammeter should be capable of reading upto ·02 or ·01 of an ampere,

ORAL QUESTIONS

Define electro-chemical equivalent of an element. What is its relation with chemical equivalent? What is electolysis and how does it take place? Why do you acidulate water in electrolysing it? How do you find the pressure of hydrogen gas within the collection tube? What is the vapour pressure of water? Is it the same at all temperatures? Suppose you are supplied with c.c.e. of hydrogen; can you utilise the principle of electolysis in measuring a current?

Copper Voltameter

This is a simple apparatus for measurement of electric current depending upon the electrolysis of copper sulphate solution. Fig. 277 represents a practical form of copper voltameter. G is a glass pot containing the copper sulphate solution and provided with an ebonite lid. The anode consists of two copper plates AA connected together and having a binding screw B at the top of the lid. The cathode is a single plate of copper K placed in between the anode plates and is projected a little through a hole in the lid. Another binding screw is fixed at this projected part. The cathode plate can be taken out of the voltameter whenever required. On passing

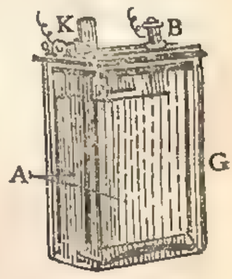


Fig. 277

electric current through the solution, copper is deposited on the cathode, which is the negative terminal. Hence the cathode plates continuously increases in weight as long as the current passes. The weight w of copper ions deposited on the plate is given by the following equation,

$$w = Czt$$

where C = current in amperes.

t = period of current flow in seconds.

z = electro-chemical equivalent of copper, which is the amount deposited when one ampere flows for one second.

A copper voltameter is used in determining the constant of a Tangent Galvanometer.

Date— **EXPERIMENT 145**

To Determine the Reduction Factor of a Tangent Galvanometer

Theory—If a current of C amperes flows through a properly adjusted tangent galvanometer producing a steady deflection θ of the needle, then $C = 10K \tan\theta$. The constant K is called the reduction factor of the tangent galvanometer and is equivalent in magnitude to the current producing a steady deflection of 45°.

If this current is made to pass through a copper voltameter for t seconds producing thereby an increase in weight of the cathode plate by w gm., then

$$C = \frac{w}{zt} = 10K \tan\theta, \text{ where } K = \frac{w}{10zt \tan\theta}.$$

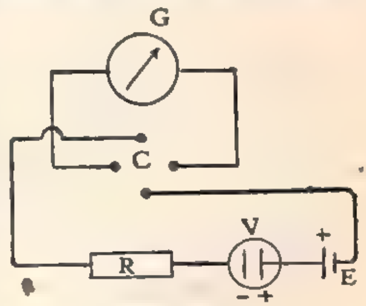
Apparatus—A tangent galvanometer, a copper voltameter, balance, weight box, a rheostat, a stop-watch, a commutator, a storage cell and some connecting wires.

Procedure—Connect the positive terminal of a storage cell E to the anode of the copper voltameter and its negative terminal to the binding screw of a commutator C. Join the cathode or the deposition plate of the copper voltameter V through a rheostat R to the other binding screw of the commutator as shown in Fig. 278. Join the leads from a tangent galvanometer G to other terminals of the commutator. Pour copper sulphate solution into the voltameter pot until the plates are wholly immersed.

Now level the galvanometer in the following way. Place a spirit level on the top glass cover parallel to the line joining two of the levelling screws and bring the bubble at the centre by adjusting any one or two of the screws. Place the spirit level at right angles to its previous direction and again bring the bubble at the centre by adjusting the third screw. When the galvanometer is property levelled the needle becomes free to oscillate. Rotate the circular coil about the vertical axis so that the pointer of the needle reads 0°—0°. Close the commutator circuit and adjust the resistance of the rheostat such that the deflection of the galvanometer needle is very nearly

45°. Now reverse the current and observe the deflection. If the deflection is very much different, it indicates that the plane of the galvanometer coil is not parallel to the magnetic meridian or that there is some twist in the suspension fibre of the needle. Proper adjustment should be made so as to obtain equal deflection on both the sides on reversing the current.

Take out the cathode plate of the voltameter and rub it thoroughly with sand paper. Wash it with dilute nitric acid, then with caustic soda solution and finally with distilled water. After carefully drying under air blast so as to remove all traces of moisture, weigh it in a balance very accurately. The weight should be taken either with the method of oscillations or with a rider. Let the weight be W_1. Now put the cathode plate within the voltameter. Close the commutator and simultaneously start a stop-watch. Note the deflection of the needle. Pass the current for half-an hour reversing its direction with the commutator every five minutes. Note the deflection of the needle every time just before the reversal of the current.



Fig, 278

After stopping the current take out the negative plate, wash it under a mild current of water. After again drying it under a fan, accurately weigh in a balance. Let it be W_2. The difference of the two weights gives the amount of copper deposited, which is, say, w. Then knowing the electro-chemical equivalent of copper, which is 0·000529, find from the formula the average current through the voltameter. Finally, from the equation $C = 10K \tan\theta$, calculate the value of K. Here θ is mean deflection.

Results

Initial weight of the copper plate $= W_1$ gm.
Final weight of the copper plate $= W_2$ gm.
$\therefore$ weight of copper deposited $= W_2 - W_1 = w$ gm.
Time during which current flows $= t$ secs.

$$C = \frac{w}{0.000329 \times t} \text{ amp.}$$

Deflection of the needle every 5 minutes $= \theta_1, \theta_2, \theta_3, \theta_4, \theta_5$
Hence mean deflection $= \theta°$

$$\therefore \quad K = \frac{w}{10 \times 0.000329 \times t \times \tan\theta} \text{ C.G.S. units.}$$

Discussions—Proper care should be taken to connect the negative end of the circuit to the cathode of the voltameter. If the connection be reversed the cathode plate becomes blackened. Be-

fore passing the current the cathode plate should be made entirely free from oil or grease for a steady deposition of ions. The current passed through the voltameter should never exceed the maximum limit assigned to a particular voltameter. The current should be passed for a considerable period for a measurable quantity of deposited ions. The weight of the cathode should be taken each time very accurately.

ORAL QUESTIONS

What is the reduction factor of a tangent galvanometer? What is the principle of action of a copper voltameter? Is there any direction in connecting a copper voltameter in a circuit and why? Why a voltameter is used in such a circuit in perference to an ammeter? It is possible to find the reduction factor absolutely from the specification of a galvanometer? What is meant by e.c.e. of a substance? What is the relation between chemical equivalent and electrochemical equivalent of an element?

Date— EXPERIMENT 146

To Measure a Resistance with a Tangent Galvanometer

Theory—If the deflection obtained with a tangent galvanometer meter in a circuit does not change when an unknown resistance at any part of the circuit is replaced by a known resistance, all other conditions remaining unchanged, then the unknown resistance is equal to the known resistance.

Apparatus—A tangent galvanometer, battery, a rheostat, a commutator, a resistance box, a three-way key and an unknown resistance coil.

Procedure—Make the circuit as shown in Fig. 279 in which B represents the battery, Rh the rheostat, K the commutator, G the tangent galvanometer, T the three-way plug key, R the resistance box and X the coil whose resistance is to be determined. Put the coil X of unknown resistance into the circuit by the three-way key and observe the deflection of the galvanometer. If the deflection is too large or too small, adjust the rheostat to get a measurable deflection. Read the deflection accurately avoiding parallax. Next introduce the resistance box R into the circuit by three-way key, and by repeated trials insert a resistance from the box so as to get an equal deflection. The rheostat during this operation must not be disturbed. Reverse the current and take similiar set of readings. Then the mean value of the known resistance is equal to the unknown.

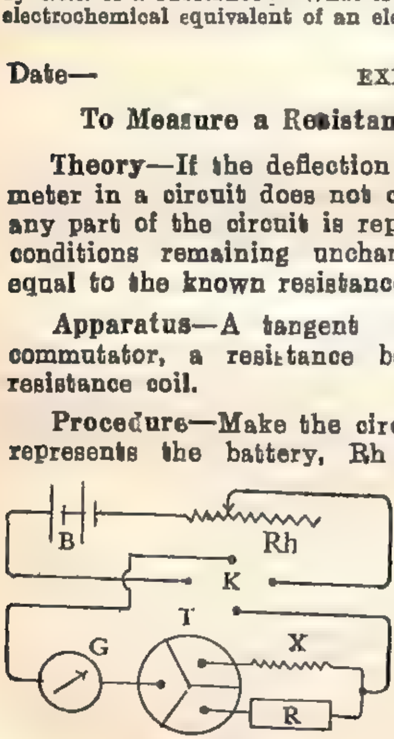


Fig. 279

Results—

No. of obs.	Current Direct or Reverse	Deflection of Pointer end A	Deflection of Pointer end B	Mean deflection	Resistance unknown ohm x	Resistance known ohm	Remark
1.							
2.							
3.							

Discussions—Resistances, whose values are considerably large cannot be accurately determined by the method of substitution. Although the galvanometer can be set for any deflection, it ought to be adjusted for a deflection of nearly 45°, at which it gives most accurate results.

Date— EXPERIMENT 147

To Compare two Resistances with a Tangent Galvanometer

Theory—If a resistance R_1 is connected in a series with a tangent galvanometer of resistance G and a cell of e.m.f. E and internal resistance r, producing a deflection θ_1, then according to Ohm's law.

$$\frac{E}{R_1+G+r}=K\tan\theta_1$$

Again if the resistance R_1 is replaced by another resistance R_2 producing a deflection θ_2 other things remaining unaltered, then

$$\frac{E}{R_2+G+r}=K\tan\theta_2$$

From the two equations,

$$\frac{R_2+G+r}{R_1+G+r}=\frac{\tan\theta_1}{\tan\theta_2} \quad \ldots \quad \ldots \quad (1)$$

Knowing G, r, θ_1 and θ_2 the ratio R_2/R_1 is found. In fact, r is small as compared to R + G, then,

$$\frac{G+R_2}{G+R_1}=\frac{\tan\theta_1}{\tan\theta_2} \quad \ldots \quad \ldots \quad (2)$$

Apparatus—A tangent galvanometer, a commutator, a battery, a three-way key, two resistance coils and some connecting wires.

Procedure—Make the arrangement of apparatus exactly as in the preceeding experiment, the known and unknown resistances, being replaced by two resistances R_1 and R_2 and the rheostat is dispensed with. With R_1 in the circuit, note the deflections for the two ends of the needle of the galvanometer with direct and reversed currents. Repeat the same operation with R_2 in the circuit. If r is actually very small, then from equation 2, find the ratio of R_2 and R_1 having given the value of G. If G and r are supplied, equation 1 may be applied. If G and r are required to be determined, then proceed on with the experiment similar to the varification of Ohm's law from which $G+r$ is known.

Results—

No. of obs	Resistance in circuit	Deflection of Needle: Direct, End I	Direct, End II	Reverse, End I	Reverse, End II	Mean Deflection in°	Q' ohms	$\frac{R_2}{R_1}$ Ratio
1.	R_1							
2.	,,							
3.	,,							
4.	R_2							
5.	,,							
6.	,,							

Discussions—This procedure is suitable when R_1 and R_2 are not very much greater than each other. If $R_1 >> R_2$ then θ_2 is much greater than θ_1 and hence angles cannot be measured with an equal order of accuracy. For a fairly accurate measurement of the ratio, the resistance of the galvanometer should be taken into consideration.

Oral Questions

How does a tangent galvanometer work? What is the reduction factor? What are preliminary adjustments of a tangent galvanometer before working with it? How can you measure current in amperes with a tangent galvanometer? What is the galvanometer constant? How does this method differ that from of Wheatstone's Bridge?

Suspended Coil Galvanometers

These galvanometers belong to the most sensitive types capable of the measuring millionth part of an ampere or even less. The apparatus consists of a small rectangular metal frame C on which a coil of fine insulated copper were is wound (Fig. 280). One terminal of the coil is soldered to a fine strip F of phosphor-bronze alloy by which it is suspended from a metal beam. The other terminal of the coil is connected to a fine metal spiral S. The upper beam and the lower metallic rod are connected to two binding screws at the base of the instrument (Fig. 281). There is a small mirror m fixed at the top of the coil.

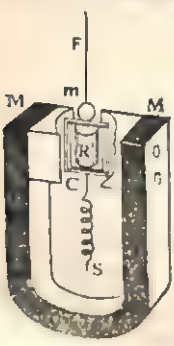


Fig. 280

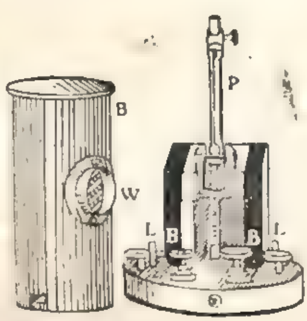


Fig. 281

The coil is suspended freely in a cylindrical space within the pole pieces of a strong horse-shoe magnet M, the pole pieces of which are cut into a concave cylindrical shape. A soft iron cylinder R is placed symmetrically within the coil without touching it and is kept in a position by a frame at the back of the instrument. The

whole system is preserved in a cylindrical metal cover B having a round glass window W which is placed opposite the mirror.

In order to work the instrument, it is at first levelled so that the coil swings freely. A lamp and a scale are adjusted such that a beam of light from the lamp after being reflected by the mirror M is focussed on the scale. If a current is now sent through the coil, the latter would rotate in proportion to the strength of the current which is indicated by the movement of the spot of light. If C be the current strength and d the deflection on the scale, C is proportional to d, that is, $C=kd$ where k is a constant depending on the type of the galvanometer. [For the principle of action vide Basu & Chatterjee's Intermediate Physics]

Since the instrument is designed to detect and measure a very small current (10^{-6} to 10^{-9} ampere), parts of the galvanometer particularly the suspension strip and the fine spiral are liable to burn out by a current in case of careless handling. Students are *particularly warned against* such a damage of the galvanometer during their course of experiments. To ensure some safety, a galvanometer is very often used with a shunt, the purpose of which is to divert a small fraction of the current through the galvanometer.

The pattern just described is known as D' Arsonval type of galvanometer. There are other varieties of suspended coil galvanometers. But in general, the principle of action is same; but their sensitiveness to current and potential difference changes with pattern.

Galvanometer Resistance and its Measurement.

By the term galvanometer resistance, we mean the resistance of the coil of the galvanometer including the suspension strip and the balancing spiral. Depending upon the type of the galvanometer, the resistance may be of any value between 5 ohms to about 2000 ohms. There are various methods of measuring galvanometer resistance, of which a very simple method is given below (Fig. 282).

As is evident from the diagram, the cell of e.m.f. E sends a current through a commutator K into the circuit consisting of a resistance box in which a resistance R_1 is put. The circuit also contains a small resistance r having at its parallel another resistance box having a resistance R and a galvanometer of resistance G.

The equivalent resistance of G and R is $G+R$. If P be the equivalent resistance of $G+R$ and r, which are parallel resistances, then

$$\frac{1}{P}=\frac{1}{G+R}+\frac{1}{r}=\frac{G+R+r}{(G+R)r} \quad \text{whence } P=\frac{(G+R)r}{G+R+r} \qquad \dots (1)$$

Now if we make r negligibly small as compared to G, R having any value, the denominator of equ. (1), may be put equal to $G+R$. Then the value of $P=r$. Let $G+R$ be R_1. Thus the current C flowing in the circuit is given by,

$$C=\frac{E}{R_1+r} \text{ being independent of any change of R.}$$

The potential difference at the ends of r is evidently Cr, Call this potential difference V.

Date

EXPERIMENT 148

To Measure the Resistance of a Galvanometer with Half deflection Method

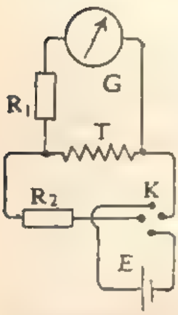


Fig. 282

Theory—If a galvanometer of resistance G is connected in series with a resistance box R and if the combination is connected in a circuit in parallel with a low resistance shunt r such that the equivalent resistance of the circuit is *very nearly* equal to that of the shunt, then, on passing a suitable current through the combination, we get,

$$\frac{V}{G} = K\theta = K_1 d$$

where V = potential difference across the shunt, d = deflection of the spot of light on the galvanometer scale when there is no resistance in the box. If now, on inserting a suitable resistance R ohms in the resistance box, the deflection becomes half the original value,—

Then $$\frac{V}{G+R} = K\frac{\theta}{2} = K_1\frac{d}{2}$$

Combining the two equations, we get $G = R$.

Apparatus—A suspended coil galvanometer, a resistance box, a fractional resistance box, a rheostat, commutator, cell and connecting wires.

Procedure—Make the circuit connections as shown in the Fig. 282, r representing a fractional resistance box used as a shunt R the resistance box in series with the galvanometer, K the commutator, R_1 the rheostat and E an exide cell.

Put the rheostat to its highest possible value and make the series resistance R zero. Then make the resistance in the fractional resistance zero and complete the commutator circuit. No deflection of the galvanometer is observed. Now take out a fractional resistance such that the deflection of the galvanometer is between 10 to 15 cm. on the scale. Now adjust the series resistance R to a value so that the deflection of the galvanometer becomes *exactly half*. Then the resistance so adjusted is equal to the galvanometer resistance. Reverse the current and get similar readings. Tabulate the readings as shown in the table.

Again give the series resistance R a zero value and change the shunt resistance *slightly* so as to get another deflection on the scale. Now adjust the series resistance to make the deflection half. In this way take a number of readings and find the mean value of the resistances so found.

Results—

No. of Readings	Current	Resistance R_1 ohms.	Resistance r ohms.	Resistance R ohms.	Deflection cm.	Mean Resistance ohm.
1*a*	direct	300	·1	0	6·2	
1*b*		,,	,,	101	3·1	
2*a*	reverse	...	...	...	...	100
2*b*	...	...	...	...	...	
3*a*	direct	250	·05	0	7·6	
3*b*	...	,,	,,	100	3·8	

Discussions—The resistance which is used as a shunt of the galvanometer circuit should be so small as not to sensibly alter the potential drop across it for any change of series resistance R used with the galvanometer. Hence the lower is the value of r, the more accurate is the result.

ORAL QUESTIONS

What do you mean by the galvanometer resistance? Is it a fixed quantity for all galvanometers? What is the difference between a suspended magnet galvanometer and a suspended coil galvanometer? Can you apply the half deflection method to find the resistance of a tangent galvanometer, if not, why? What type of a galvanometer is more sensitive to deflections,—a galvanometer having a higher resistance and the other of a lower resistance, other specifications being same?

Post Office Box—For a direct measurement of resistance a Post Office Box is used (Fig. 283). It is difficult to say why the name Post Office Box was given to it, But it may be surmised that the method is so mechanical that with a little practice, a lay man can work with it.

Date— **EXPERIMENT 159**

To Measure the Resistance of a Wire using Post Office Box

Theory—If a null point is obtained with a resistance r_1 in the arm Q and a resistance r_2 in the arm P and if r_3 be the resistance in the third arm R, then the unknown resistance S is given by

$$S = \frac{r_3}{r_1} r_2$$

Apparatus—A P.O. box, a rheostat, cell, galvanometer and an unknown resistance.

A P.O. box consists of a number of fixed resistances all connected in series much the same way as a resistance box of larger type. The group of resistances may be divided into three parts P, Q and R, called the arms of the P.O Box (fig. 284) The first two arms P and Q are identical in construction, each containing a series of resistances 10,100 and 1000 ohms. interconnected by thick metal studs, as shown by black parts. These arms are called *ratio*

arms. There is a binding screw at each end of the ratio arms. The third arm R contains a number of resistance coils usually ranging from 1 to 4000 ohms in such steps that any integral value of resistance from 1 to 10,000 may be introduced in this arm. The free end of the third arm at B is provided with another binding screw. There are two tapping keys K_1 and K_2 at the bottom provided with binding screws at D and A, which on being depressed make metallic contacts with the points D and A respectively.

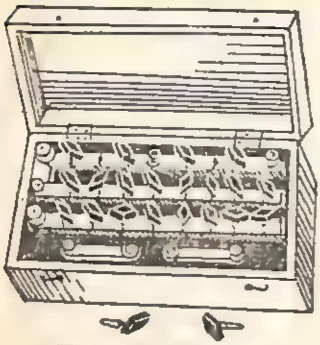


Fig. 283 P.O. Box

Procedure—Connect the terminals of the resistance S to be measured to the points D and B of the P.O. box and connect terminals of the galvanometer between B and A' (A' being connected to the point A through the tapping key K_2 (Fig. 284). Shunt the galvanometer with a small resistance coil if necessary. The poles of the cell E are connected through an adjustable rheostat Rh to the points C and D'. (D' being connected to the point D through a tapping key K_1).

Take out resistances 10 and 10 from the ratio arms and put the maximum possible resistance in the rheostat. Press the battery key K_1 and then press the galvanometer. Next take out the highest resistance in the third arm and press the keys in a similar manner. If the deflection be in opposite direction then the connection is correct.

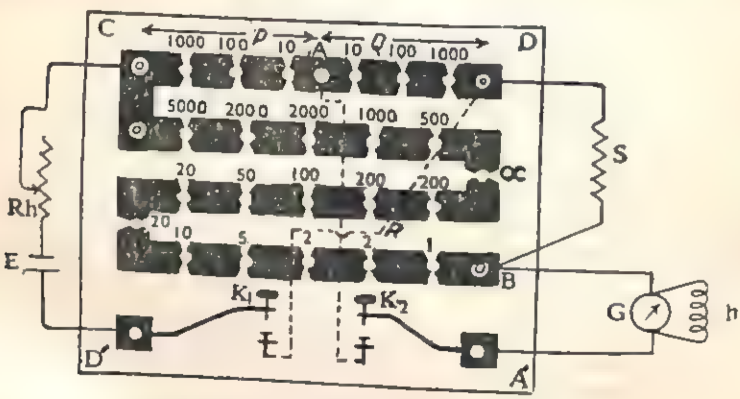


Fig. 284—Connections of a P. O. Box

By trial find a resistance, say R_1, in the third arm, such that there is no deflection in the galvanometer when you close the circuits. Then the unknown resistance S is given by

$$S=\frac{10}{10}R_1 \text{ or } S=R_1.$$

If you have not obtained the null point with any resistance or a group of resistances in the third arm, then the unknown resistance is partly integral and partly fractional. Then there must be two consecutive integral values of resistances in the third arm between which the resistance S lies. By trial find any two consecutive resistances in the third arm for which the deflections of the galvanometer are in opposite directions. Let these resistances be R and R + 1. Now take out the resistance of 100 ohms instead of 10 in the arm P. The null point should occur when the resistance in the third arm is of some value between 10R and 10(R + 1): let this value be say R_2. Then the unknown resistance is given by,—

$$S=\frac{10}{100}R_2 \text{ or } S=\frac{1}{10}R_2$$

The resistance is thus found correct to one decimal place.

If you have not yet obtained the null point even at this stage then you would get two consecutive resistances say R_3 and R_3+1 for which the galvanometer will be deflected in opposite directions. Now take out resistance of 1000 ohms in P instead of 100. If now the balance point is obtained with resistance R_4 in the third arm, then

$$S=\frac{10}{1000}R_4 \text{ or } S=\frac{1}{100}R_4$$

The resistance found is correct to two places of decimals.

Results—

Resistance in ohms			Direction of Deflection	Inference Third arm resistance is
1st arm Q	2nd arm P	3rd arm R		
10	10	∞	right	too large
"	"	0	left	too small
				∴ connection is correct
"	"	50	right	too large
"	"	10	"	"
"	"	5	"	"
"	"	2	left	too small
"	"	3	right	too large
"	"			Resistance > 2 and < 3
10	100	30	right	too large
"	"	20	left	too small
"	"	25	left	"
"	"	28	right	too large
"	"	26	right	"
				Resistan > 2·5 and < 2·6
10	1000	260	right	too large
"	"	250	left	too small
"	"	255	left	"
"	"	258	right	too large
"	"	257	right	"
"	"	256	null	Resistance = 2·56 ohms

Discussions—This method of measuring a resistance gives a greater accuracy than the ordinary metre bridge method. If the galvanometer is too sensitive then even with a ratio 1000 to 10 the exact null point may not sometimes be attained. To get the accuracy still further a method known as the method of deflection may be applied to get another decimal place but this method is outside the course of Intermediate standard.

ORAL QUESTIONS

What is the principle on which a P. O. Box works? Where are the arms of the box? What are the functions of the ratio arms? Where are the resistance coils? How is it that when a plug is taken out, the corresponding resistance is introduced into the circuit? What for are the two tapping keys? Is there any direction regarding pressing of such keys? Can you suggest why it is called a P. O. Box?

Measurement of Electromotive Force

Potential difference between any two points of a circuit carrying a current is ordinarily measured with a moving coil voltmeter. It must be remembered that some current, however small it might be, is taken by a voltmeter to record any deflection. The voltmeter, in taking up a little current from the circuit, alters the distribution of current in it and causes the potential difference to be changed by a little amount. The higher is the resistance of the voltmeter, the less is the current passing through it for a given potential difference and hence the less is the change of the distribution of current through other parts of the circuit. In this sense an ideal voltmeter is one whose resistance is infinitely large. An electrostatic voltmeter of which quadrant electrometer is a type satisfies this condition. But this class of instruments cannot be used accurately for low voltage measurements.

Potentiometer—This apparatus is used for comparing electromotive forces of cells or potential differences of different parts of

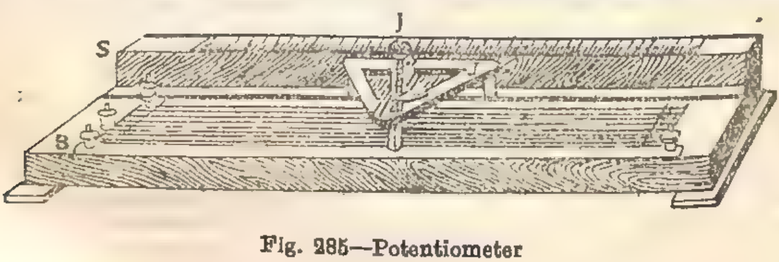


Fig. 285—Potentiometer

electrical circuits It takes no current from the circuit under examination causing thereby no change in the current distribution and hence it can measure the true value of the e.m.f. or potential difference.

It consists of rectangular wooden board on which a number of wires of uniform cross-section, each one metre long is stretched parallel to each other (Fig. 285). They are joined in series by means

of copper or brass strips so that the combination behaves as a single piece of wire of a length equal to the sum of the lengths of all the wires. The free terminals of the first and the last wire are provided with two binding screws. There is a raised platform at one edge of the board on which a metre scale S is fixed and is placed parallel to the wires. A jockey J, fitted with an adjustable tapping key, provides a contact at any point of the wire. The jockey always moves in contact with a brass strip to which is fixed a binding screw.

Principle of Measurement of E.M F.

The principle of working of a potentiometer can be best understood, if we examine its mode of connections in an electrical experiment. Let a cell of e.m.f., E be connected to the ends of the potentiometer wire as shown in Fig. 280. A resistance box or a rheostat with a key is included in this circuit. This is called the primary circuit. When the key is closed, a current passes through the potentiometer wire and this current is known from a knowledge of the e.m.f. and the resistance of the circuit.

Since the wire of the potentiometer is uniform, the resistance of the potentiometer is proportional to its length. If L be the total length of the wire (usually 1000 cm.) and if ρ be the resistance per unit length of the wire and further if r be the resistance introduced in the rheostat, then current C in the primary circuit is given by,

$$C=\frac{E}{L\rho+r}=\frac{E}{1000\rho+r}$$

The difference of potentials v per unit length of the potentiometer wire $C\rho$. Taking A to be the positive potential end of the cell, the difference of potentials continuously increases from this point towards the other end of the wire. The maximum potential drop at the ends of the potentiometer wire is given by,

$$C\times 1000\rho=\frac{E}{1000\rho+r}\times 1000\rho=1000v$$

The potential drop per unit length of the potentiometer wire is called the voltage sensitivity of the bridge wire.

Date—

EXPERIMENT 150

To Compare the Electromotive Forces of two Cells with a Potentiometer

Theory—If l_1 is the distance of the bridge-wire at which a null point is obtained with a cell of e.m.f. e_1, and l_2 is the corresponding distance with another cell of e.m.f. e_2, then

$$\frac{e_1}{e_2}=\frac{l_1}{l_2}$$

Thus knowing any one of the e.m.f.s. and the ratio of the lengths, the other e.m.f. can be determined.

Apparatus—A potentiometer bridge, a storage cell, a rheostat, plug key, galvanometer, Daniell's cell, Leclanche's cell, a three-way key and an adjustable high resistance.

Procedure—Connect the positive pole of the storage cell E to the first terminal A of the potentiometer wire and negative pole to the other end through a plug key and a rheostat r as shown in Fig. 280. Connect also the positive poles of the cells to be compared, usually a Daniell's and a Leclanche's cell to the same point A and their negative poles to the two binding screws of a three-way plug key K. Connect the common point of this key with a wire to one end of a galvanometer G. Connect the other end of the galvanometer to the jockey B of the potentiometer through an adjustable high resistance R.

To begin the experiment put the rheostat to its minimum value and adjust R to a *high resistance*. Close the key of the storage cell circuit and insert the plug of the three-way key so as to include the cell of e.m.f. e_1 in the galvanometer circuit. Shift the jockey very near A and press it so as to be in contact with the wire. Observe the direction of deflection of the galvanometer. Suppose the deflection is to the left. Now shift the jockey to the other end of the bridge wire and press it again. If the deflection happens to be in opposite direction, that is to the right in this case, then the cell of e.m.f. e_1 is properly placed in the circuit. If it is otherwise, either the poles of the cells E and e_1 are connected wrongly or that the cells have been interchanged by mistake. A similar examination of the other cell of e.m.f. e_2 is necessary by changing over the plug of the three-way key.

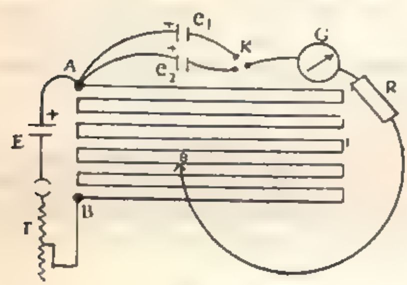


Fig. 286

After ascertaining the condition that opposite deflections are obtained at the ends of the bridge wire with either of the cells, put the plug of the three-way key so as to include one cell in the circuit. By trial find the null point somewhere on the bridge wire and take the reading. Similarly, find the null point for the other cell. The cell for which the null point reading is greater has a higher e.m.f. If you observe that both these null points happen to lie on the second or third wire of bridge, slightly increase the resistance of the rheostat so that the null point corresponding to the cell of larger e.m.f. is shifted to sixth or seventh wire.

Now find the null points of the two cells accurately by bringing down the resistance in R to zero, without changing the resistance of the rheostat.

Let l_1 be the length of the wire at which the null point is obtained for the Leclanche's cell of e.m.f. e_1 and l_2 that corresponding to the Daniell's cell of e.m.f. e_2, then the ratio of the lengths gives the ratio

of the e.m.f's. Take a number of such ratios by slightly diminishing the value of rheostat resistance each time, until the null point is obtained on the last wire.

Results—

No of observations	Length l_1 cm.	Length l_2 cm.	l_1/l_2	Mean Ratio e_1/e_2
1.	441·2	396·7	1·37	
2.	600·2	435·2	1·38	
3.	792·3	526·8	1·39	1·38
4.	870·1	630·5	1·38	
5.	912·0	660·8	1·38	

Taking the e.m.f. e_2 of the Daniell's cell to be 1·09 volts the e.m.f. e_1 of Leclanche's cell is $1·09 \times 1·38 = 1·504$ volts.

Discussions—The rheostat should be so adjusted as to get the null points at large lengths, because in such cases a higher percentage of accuracy is obtained in the measurement of a length. The storage cell used in the potentiometer circuit must have a higher e.m.f. than any one of the cells to be compared. Ordinarily the series resistance in the galvanometer circuit should be large to guard against the damage of the instrument; near about the null point the resistance should be decreased to increase the sensitivity of the galvanometer.

Oral Questions

Why is a potentiometer used in comparing the e.m.fs. of cells? Can a moving coil voltmeter be substituted for the galvanometer in this experiment? Explain the condition of a null point with a potentiometer. What sort of galvanometer is most suitable in a potentiometer circuit? Why is a variable high resistance used in the galvanometer circuit? With connections properly done it is sometimes found that the deflection is in the same direction all over the bridge wire; what conclusions may be derived out of such an observation?

Date—

Experiment 151

To Determine Electro-chemical Equivalent of Copper

Theory—If a current of C amperes flows through a copper voltameter in t seconds producing a deposit of W gm. of copper on the cathode, then the electro-chemical equivalent z of copper is given by

$$z = \frac{W}{Ct} \text{ gm. per coulomb.}$$

The current C is to be known by measuring accurately the drop of potential across a standard resistance put into the voltameter circuit.

Apparatus—A copper voltameter, a sensitive galvanometer, a standard 5 ohm resistance, a stop-watch, a potentiometer, standard cell, two accumulators, two rheostats, some connecting wires, plug key and a variable high resistance, a two-way key.

Procedure—Make the electrical circuit in a manner as shown in Fig. 287 in which P represents the potentiometer with its terminals

at M and N. Connect the positive terminal of an accumulator A through a wire at M and its negative terminal through a rheostat R_1 and a plug key K_1 to the point N of the potentiometer.

Make another circuit cosisting of an accumulator B, copper voltameter V, a rheostat R_2 and the standard resistance r. Connect the negative terminal of the cell to the cathode plate of the copper voltameter through the key K_2.

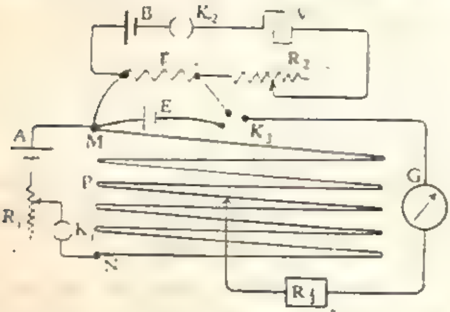


Fig. 287

Connect the high potential end of the standard resistance r to the end M of the potentiometer and their negative terminals to the binding screws of a two-way key K_3. Connect also the common return of the key to the sliding jockey through a galvanometer and a variable high resistance R_3.

Put in keys K_1 and K_3 so as to include the standard cell into the circuit. Adjust the rheostat R_1 so that the null point is obtained on the last wire of the potentiometer. Keep the variable resistance R_3 to a high value at the beginning but when null point is nearly obtained bring down the resistance R_3 to a zero value. Take two or three such readings for the same value of R_1. The mean value gives the null point corresponding to the standard cell. Let the null point on the wire be *l cm.*

Then place a test cathode plate into the voltameter and close the key K_2. Then operate the two-way plug key so as to include R_2 to get the null point at a measurable distance on the bridge wire. Care must be taken so as not to exceed the maximum allowable current through the voltameter.

Clean the actual cathode plate with sand paper, wash with dilute nitric acid and with distilled water and finally dry it by passing hot air from a blower. When the plate is completely dried, weigh it in a balance *accurately*. Let the weight be W gm.

Place the plate within the voltameter with the key K_7 open. Start the stop-watch simultaneously with the closing of the voltameter circuit and allow the current to flow for a known interval t, say 20 to 30 minutes. During this interval find the balance point over the wire a number of times with standard resistance in the potentiometer circuit. Let the mean null point be d cm.

Take out the cathode plate carefully and wash it under a stream of cold water. Dry and finally weigh. Let the weight be W_1 gm.

Results—

Reading of the null point with the standard cell in the circuit
= 946'6 cm. (mean value)

The E. M. F. of the standard cell = 1·088 volts.

$\therefore$ Potential drop per cm. of the bridge wire $= \frac{1·088}{946·6} =$ ·00107 volt.

Initial weight of the cathode plate = 184·32 gm.
Reading of null point with the standard resistance in the circuit = 570·1 cm. (mean value)
Final weight of the plate = 185·04 gm.
$\therefore$ Gain in weight of the cathode plate = 0·72 gm.
Interval of the current flow = 30 minutes.
The value of the standard resistance = 5 ohms
Potential difference at the terminals of the standard resistance of 5 ohms resistance = ·61 volt.

$\therefore$ Calculated current in the voltameter circuit = ·122 amp.

$\therefore \quad z = \frac{·72}{·122 \times 30 \times 60} =$ ·000326 gm. per coulomb.

Discussions—There is a maximum limit of the current strength which can be sent through a copper voltameter depending upon the area of the cathode surface under the copper sulphate solution. The limit should never be exceeded. If the current is sent through the voltameter for a longer period, the more is the deposition on the cathode surface and consequently the less is the error in determining the current strength. While searching for the null point, the resistance in the galvanometer circuit should be initially high but to get the null point the variable resistance ought to be put equal to zero. If the copper sulphate solution is to be prepared, 15 to 20 gms of copper sulphate crystals are to be dissolved in about 100 c.c. of the solution. The standard value of e.c.e. of copper is 0·000329 gm. per coulomb. Hence the error is slightly less the than 1 per cent.

ORAL QUESTIONS

What is meant by E. C. E. of an element? What is the difference between chemical equivalent and electro-chemical equivalent? Is it possible to measure e.c.e. of an element from a knowledge of e.c.e. of another element? Why is current measured by the potentiometer method and not by ammeter.

EXPERIMENT 152

Date—

To Measure the E.M.F. of the given Cell with a Potentiometer of known resistance having given a milliammeter and an accumulator.

Theory—If a null point is obtained with a given cell of e.m.f. E volts at a distance l cm. on the potentiometer wire of resistance ρ ohms per unit length carrying a current C amp. Then $E = Cl\rho$ volts.

Further if r be the total resistance of a potentiometer wire of length 1000 cm. and if C′ be the reading in a milliammeter, then $\rho = r/1000$ and $C = C'/1000$. Then $E = Crl \times 10^{-6}$ volts.

Apparatus—A potentiometer, a suspended coil galvanometer, a milliammeter, accumulator, a standard cell, key, high resistance, a rheostat and connecting wires.

Procedure—The connections are shown in Fig. 288. Connect the pole marked + of the milliammeter to the positive pole of the accumulator.

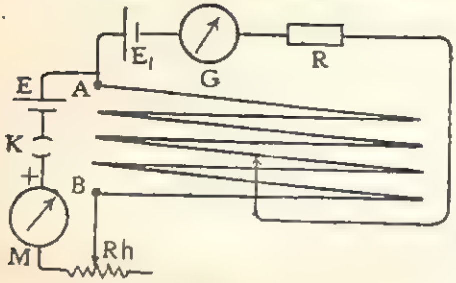


Fig. 288

Put a high resistance into the galvanometer circuit in series and also introduce a suitable value of the rheostat so that you get the null point on the 9th or 10th bridge wire. To get the null point finally bring the series resistance gradually to a zero value to increase the sensitiveness of the galvanometer. Take the reading of milliameter.

Change the resistance of the rheostat slightly *to a smaller value* and find another null point. Every null point should be found twice. In this way take three to four pairs of readings and tabulate the values in the following way.

Results—

No. of readings	Current in milliamp	Null pt cm.	Resistance of bridge wire	Calculated E.M.F. volts.	Mean E.M.F. volts.
1.	...	...	...	...	
...	...	...	...	...	...
6.	...	...	...	...	

Discussion—The milliammeter should be connected in the potentiometer circuit with due consideration of its terminals, which are marked + and −. Any zero error of the instrument should be taken into account in recording its readings. The null point should be selected anywhere on the last three wires of the potentiometer.

Date—

EXPERIMENT 153

To Compare the E.M.Fs. of Voltaic cells by the method of Sum and Difference

Theory—If E_1 and E_2 are the e.m.fs. of two cells and if they are connected in series through a resistance and a tangent galvanometer, then

$$\frac{E_1 + E_2}{R} = K \tan \theta_1$$

where R = total resistance in the circuit, K = reduction factor of the tangent galvanometer and θ_1 = deflection of the needle.

If now one cell of e.m.f. E_2 is reversed other factors remaining same, then

$$\frac{E_1 - E_2}{R} = K \tan \theta_2$$

where θ_2 = deflection in the second case. Combining the two equations,

$$\frac{E_1+E_2}{E_1-E_2}=\frac{\tan\theta_1}{\tan\theta_2} \quad \text{where} \quad \frac{E_1}{E_2}=\frac{\tan\theta_1+\tan\theta_2}{\tan\theta_1-\tan\theta_2}$$

Apparatus—A tangent galvanometer, two cells (a Bichromate cell and a Leclanche's cell), a rheostat, a commutator.

Procedure—Connect two cells E_1 and E_1, in series and connect the free terminals of the combination to a tangent galvanometer through a rheostat and a commutator K as shown in Fig. 289.

Put the maximum resistance of the rheostat and close the circuit when a small deflection of the needle is observed. Now lower the resistance of the rheostat until the deflection comes down to near about 45°. Accurately read the deflection at this stage for both of the pointer. Reverse the current and read the deflection. The mean of the deflections is say, θ_1

Next reverse anyone cell and connect as in Fig. 290 other things being kept constant and note deflections of the needle both for direct and reversed currents. Let the mean deflection be θ_2. Repeat the observations a number of times and tabulate the results.

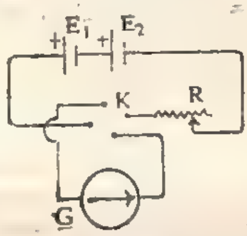


Fig. 289

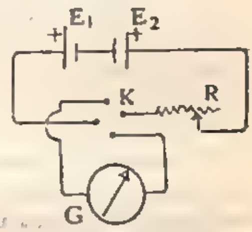


Fig. 290

Results—

No. of readings	Deflection in circuit. E_1+E_2			Deflection in circuit E_1-E_2			Ratio $\frac{\tan\theta_1+\tan\theta_2}{\tan\theta_1-\tan\theta_2}$
	Direct Deg	Reverse Deg.	Mean Deg θ_1	Direct Deg.	Reverse Deg.	Mean Deg. θ_2	
1.							
2.							
3.							

Discussions—The deflection of the needle should be adjusted nearly at 45°, when the cells are connected in series. But when the cells are reversed, the deflection becomes much less. Once when the rheostat is fixed, it *must not* be changed in a set of observations, as otherwise the ratio does not hold.

ORAL QUESTIONS

What do you mean by e.m f. of a cell? What is meant by sum and difference of e.m.fs.? Is the tangent galvanometer in this experiment used as a voltmeter? What are the cells you are using? Is there any polarisation effect when one cell is reversed?

Ohm's Law—Verification of the law by a Tangent Galvanometer and by the combination of Voltmeter and Ammeter has already been

described. But in each case, the resistance has been kept constant and a variation of potential difference with current has been shown to be constant. A more complete verification of the law consists in varying any two of the variable E, C and R while keeping the third constant, which is given below.

Date—

EXPERIMENT 154

To Verify Ohm's law with a Metre bridge, Ammeter and Voltmeter

Theory—If a current of C amp. flows through a conductor of resistance R ohms, having a difference of potentials of E volts at its terminals, then according to Ohm's law,—

(*i*) $E \propto C$ when R is constant,

(*ii*) $E \propto R$ when C is constant,

(*iii*) $C \propto \frac{1}{R}$ when E is constant.

Apparatus—A battery of 3 or 4 cells, a plug key, a rheostat, metre bridge wire, a fixed resistance of 3 to 4 ohms, a voltmeter and an ammeter.

Procedure—Make the electrical connections as shown in Fig. 291, in which B represents the battery, K a plug key, Rh a rheostat, MN a metre bridge wire, *r* a fixed resistance of 3 to 4 ohms, A the ammeter, V the voltmeter. The voltmeter may be conveniently connected between the negative pole of the battery and the jockey of the metre bridge.

The resistance of the bridge wire should be nearly 2 ohms and its actual value is to be supplied by the teacher in charge of the class. Put the rheostat to its maximum value and close the key K.

To verify the first law *i.e*, $E \propto C$, keep the jockey fixed at any position, say X. The resistance between P and X through the path *r* and XN is then kept constant. Now take the readings of the ammeter and voltmeter. Slightly alter the resistance of the rheostat and take the readings of both the meters. In this way by changing the value of the rheostat, take a few readings. It would be found that the ratio of their readings is constant, so long as the temperature of the wire is not appreciably raised by the flow of current.

To verify the second law, *i.e.*, $E \propto R$, keep the rheostat fixed in value, so that the current in the circuit as recorded by the ammeter is constant. Now place the jockey very near to N and take its reading from the scale attached. On knowing the resistance per unit length of the bridge wire, find the resistance of the portion XN. To it add the resistance *r*. Hence the resistance from D to X is found, which is say, R. Read the voltmeter which gives E. Shift the point of the jockey step by

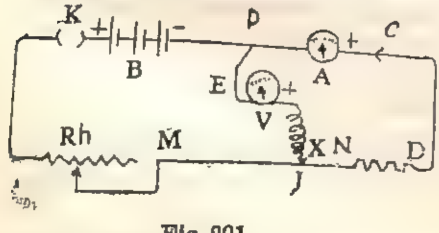


Fig 291

step, and take the readings of the voltmeter and the jockey point. It would be found that the ratio of the reading of the voltmeter to the resistance in DJ is constant.

To verify the third law *i.e.*, $C \propto 1/R$, keep the jockey of the rheostat fixed at any position and note the current in ammeter. Place the jockey near to N and find the resistance between D and the point of contact of the jockey. Record also the voltmeter reading. Next slightly *decrease* the current by the rheostat. Now slide the jockey towards M so that voltmeter gives the original reading. Thus E becomes constant. Find the resistance DX In this way take a series of values of C and R for a constant value of E.

Results—Resistance per unit length of the metre bridge wire =·021 ohm.

To verify the first law :

No of readings	Length XN cm.	Resistance of XN ohms	Resistance r ohms	Total Resistance of DX ohms	Voltmeter reading V volts	Ammeter reading C. amp	Ratio E/C
1.	55	1·176	5	6·176	4·6	·65	6·16
2.	,,	,,	,,	,,	3·15	·51	6·17
3.	,,	,,	,,	,,	...	...	6·16

To verify the second law :

No of reading	Ammeter reading C. amp.	Length XN cm.	Resistance of XN ohms	Resistance r ohms	Total resistance of DX ohms	Volt meter reading E volts	Ratio E/R
1.	·60	10	·21	5	5·21	2·6	·05
2.	,,	50	1 05	,,	6 06	3·6	·49
3.	,,	90	...	,,	...	..	·50

To verify the third law :

No. of reading	Volt meter reading E volt	Length XN cm.	Resistance of XN ohms	Resistance r ohms	Total resis-Tance of DX ohms	Ammeter reading C. amp	Product C×R
1.	...	5	---		...	...	3·8
2.	...	...	...		...	...	3·9
3.	...	...	...	,,	...	...	3·9

Discussions—Instead of the slide wire being an actual metre bridge wire, the purpose would be better served if the wire MN be a nichrome wire of length 1 metre having a resistance of about 10 ohms. In that case a large variation of resistance, voltage and current is possible. The above experiment has a speciality in as much as every quantity can be changed independent of the other two. In case of nichrome wire care should be taken not to send a current exceeding 5 ampere, as otherwise resistance per unit length of the wire would change appreciably.

Laplace's Law

Laplace's law states that the force f exerted on a magnet pole of strength m by a very short length s of a conductor carrying a current

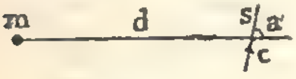


Fig. 292

C is inversely proportional to the square of the distance d and directly proportional to the length s of the conductor, the current strength C, pole strength m and sine of the angle of inclination α between the conductor and the line joining the pole to the conductor. This is some times called Ampere's Law. The law can be mathematically expressed as follows,

$$f = \frac{mC\,s\sin\alpha}{d^2}$$

It can be proved from this law that the force exerted by an infinitely long wire carrying a current C, on a magnet pole of strength m at a distance d from it is given by,

$$f = \frac{2mC}{d}$$

Hence the intensity F at a distance d from a straight wire conveying a current C is given by $2C/d$

Date

Experiment 155

To Verify Laplace's Law of Intensity due a Linear Current and hence to find H

Theory—The magnetic intensity at a distance d from a very long wire carrying a current C e. m.u. is given by $2C/d$. If this intensity be made to act at right angles to the horizontal intensity of the earth's magnetic field and a small magnetic needle be placed in the combined fields giving a deflection θ, then

$$\frac{2C}{d} = H\tan\theta \text{ or, } d = \frac{2C}{H}\cot\theta$$

If the law is correct $d \propto \cot\theta$ for given values of C and H.

Apparatus—A magnetometer box, a platform about 2 metres in length, an ammeter, a commutator, a rheostat and a battery of cells.

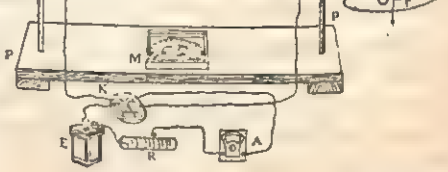


Fig. 293 Fig. 294

Procedure—Stretch a wire horizontally by the clamping screws SS fixed to the uprights of the platform (Fig. 293). Place a magnetometer box on the platform such that the needle is vertically below the wire. Rotate the platform so as to place the wire parallel to the needle. The wire is now in the magnetic meridian. The nature of the field due to a vertical straight wire is shown in Fig. 294.

Connect the terminals of the wire through a commutator K to a rheostat R, ammeter A and a battery of cells E. Pass a current of about 1 to 2 amps. through the wire by adjusting the rheostat. Measure the vertical distance from the wire to the upper surface of the glass top of the magnetometer with a metre scale. Let it be h. Take the deflection of both ends of the needle. Reverse the current and note the deflection. Let the mean deflection be θ. If s denotes the distance of the needle below the glass top, then

$$h+s=\frac{2C}{H}\cot\theta$$

The value of s is to be measured or supplied, then $h+s=d$ is known for any value of h.

Take a number of observations by changing the value of h and show the ratio $d/\cot\theta$ Finally, from the mean value of this ratio, knowing C from the ammeter and *converting it into e.m.u.*, the value of H can be found.

Results—

The distance of the needle from the glass top = ·8 cm.

No. of readings	Distance h cm.	Distance d cm.	Deflection of Needle			Cot θ	$\frac{d}{\cot\theta}$	Mean ratio
			End n deg.	End s deg.	Mean deg.			
1.	1·4	2·2	39	39	39	1·24	1·77	
2.	1·9	2·7	...	39·5	33	1·54	1·75	
3.	2.7	3·5	27	27	27	1·96	1·78	1·75
4.	3·5	4·3	25	...	32·5	1·42	1·76	
5.	4·3	5·2	29	29	29	2·90	1·77	
6.	5·1	5·8	169	16·5	16·5	3·39	1·74	

Current in ammeter = 3·0 amp.

∴ Current in e.m.u. = ·30 C.G.S.

$$\text{Hence}\quad H=2C\times\frac{\cot\theta}{d}=\frac{2\times{}^{\cdot}3}{1{\cdot}78}={}^{\cdot}34\ \text{G.C.S. unit.}$$

Discussions—For an average value of H between ·30 to ·35 C.G.S. units, large current is required for a measurable deflection of the needle. A current of 3 to 4 amperes should be better taken from the supply mains. The deflection of less than 15° should not be recorded since such values of $\cot\theta$ are fairly high and the error in measuring $\cot\theta$ is large.

ORAL QUESTIONS

What is Ampere's law? What is the nature of the field due to a linear current? Is the nature of the field altered in case of a circular current? What is the relation between practical unit of current and the C. G. S. unit? What is the effect of altering the distance of the horizontal wire carrying current on the deflection of the needle?

Production of Heat by Electric Current

When an electric current passes through resistance, heat is developed. This fact may be derived from energy principles.

Suppose that a current C flows for a time t secs. through a conductor under a difference of potentials E, all in *electromagnetic units*. The charge conveyed by a current C flowing for a time t is $C \times t = Q$, say.

Energy necessary for a charge Q to traverse a potential difference $E = EQ$ ergs. Since $Q = Ct$, the amount of work *d*one $= ECt$ ergs. This work appears in form of heat. We further know that work done W and heat developed H are connected by the equation.

$W = JH$ where J = Joule's equivalent $= 4{\cdot}2 \times 10^7$ ergs/calorie

$$\therefore \quad ECt = JH \quad \text{whence} \quad H = \frac{ECt}{J}$$

Since by Ohm's law $E = CR$,

$$H = \frac{ECt}{J} = \frac{C^2Rt}{J}$$

In an experiment, E and C are given in volts and amperes.
Now E volts $= E \times 10^8$ e.m.u. of potential difference.
and C amps. $= C \times 10^{-1}$ e.m.u. of current.

$$\therefore \quad H = \frac{E \times 10^8 \times C \times 10^{-1} \times t}{4{\cdot}2 \times 10^7} = \frac{ECt}{4{\cdot}2} = {\cdot}24 \ ECt \text{ cals.}$$

$$\text{or} \quad H = C^2 \ Rt \times {\cdot}24 \text{ calories.}$$

This principle is often utilised in measuring J.

$$J = \frac{ECt \times 10^7}{H} \text{ ergs./calorie.}$$

Date—

Experiment 156

To measure Joule's Equivalent by Electric Calorimeter

Theory—If a current of C amp. flows for a time t sec. through a resistance under a difference of potential of E volts and if the heat generated by the resistance during the interval be H calories, then

$$J = \frac{ECt}{H} \times 10^7 \text{ ergs. per calorie.}$$

Apparatus—Joule's electric calorimeter, ammeter, voltmeter, thermometer, a stop-watch, rheostat, balance, and some quantity of turpentine.

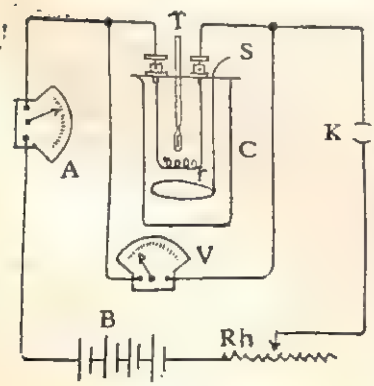


Fig. 295

Joule's calorimeter consists of a copper vessel C provided with an ebonite lid (Fig. 295). Two thick wires serving as leads pass through the lid carrying a resistance coil within the calorimeter, while their upper ends are connected to two binding screws. There is a hole at the centre of the lid for the insertion of the thermometer T and there is a second hole near at the edge through which the rod of the stirrer S passes.

Procedure—Remove the lid and weigh the calorimeter with the stirrer to the nearest decigram. Pour some quantity of turpentine oil into the calorimeter, so that the coil is fully immersed and weigh the combination also to the nearest decigram. The difference in masses gives the amount of liquid in the calorimeter. Fit the lid on to the calorimeter and connect the terminals of the resistance coil in series with a key K, battery B, rheostat Rh and an ammeter A as shown in the figure. Connect also a voltmeter V to the binding screws of the resistance coil taking care that the positive end of the meter is connected to the high potential end of the coil. Insert a thermometer through the central hole so that its bulb dips into the liquid and clamp it, if necessary. Note the initial temperature of the liquid. Now close the key K and simultaneously start a stop-watch. Pass the current and slowly stir the liquid until a rise of temperature of 5 to 6°C is attained. Accurately observe the highest temperature, stop the current and also stop the watch. Record also the readings of the ammeter and voltmeter while the current is passing.

If the radiation correction is required, make a time-temperature record of the rising and falling temperatures of the calorimeter and its contents and then make the necessary radiation correction [vide Expt. 60].

Results – (Typical)

Mass of the calorimeter and stirrer = 98 2 gm.
Mass of the turpentine, calorimeter and stirrer =
∴ Mass of liquid within calorimeter =
Specific heat of the liquid (supplied) = ·5
Sp. ht. of the material of the calorimeter = ·1
Intial temperature of the liquid = 23 5°C
Final temperature of the liquid = 30 2°C
Current passing through heating coil = ·65 amp.
Potential difference across the heating coil =
Time during which current flows = 4 min.
Heat absorbed by the liquid and calorimeter =
Heat given out by the wire =
∴ $J = 4\ 24 \times 10^7$ ergs/calorie (as observed)

Discussions—While the calorimeter and its contents are receiving heat from the resistance coil, some heat is lost by radiation and conduction. This part, if not corrected, will increase the observed value of J. The liquid within the calorimeter should be of low specific heat, as then small quantity of heat will raise it through an appreciabld rise of temperature. The radiation correction may be made by taking a time-temperature record.

ORAL QUESTIONS

What is Joule's equivalent and what is its unit? How can you measure work done in an electric circuit and what is its unit? Do you know the relation between work and power? What is the practical unit of power? How can the power of a circuit be measured? What is the effect on the value of J if radiation correction is not taken into account? How can you make radiation correction?

Date—

Experiment 157

To Trace Lines of Force due to a Linear Current and to determine H from the Neutral point

Theory—The nature of the magnetic field due to a current in a linear conductor is a series of concentric circles with the conductor as the axis. The direction of intensity is given by Maxwells cork screw rule. When lines of force due to a vertical current are traced in earth's magnetic field, their nature at some distance from the conductor is not circular due to the resultant field. A point may actually be obtained where the two fields neutralise each other, which is called the neutral point. If d be the distance of the neutral point from the axis of the conductor and C be the current flowing in it in amperes, then

$$\frac{\cdot 2C}{d} = \text{H dynes.}$$

Apparatus—A straight brass or copper rod about 2 metres long provided with binding screws at its ends, a large battery capable of sending a current of .0 amperes or the electric mains, a card board having a small hole, suitable stands, rheostat or large wire resistance, a small magnetic needle, drawing materials and an ammeter.

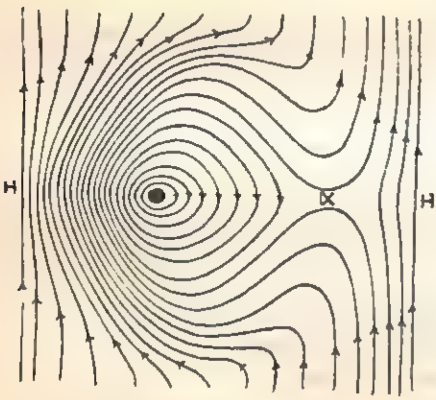


Fig. 296

Procedure—Make a round hole, just sufficient for the rod to pass at the central part of the drawing paper and fix the paper on to the board containing a similar hole. Mount the board on rigid clamps so as to remain horizontal. Pass the metal rod through the hole and keep it vertical by wooden clamps. If instead of battery electric mains are used, the rod should better have an insulating coating to avoid electric shocks while working.

Connect the poles of the battery by thick wire to the terminals of the rod through a large rheostat, ammeter and a key all in series. Keep the wires from the vertical conductor at a considerable distance from the horizontal board to minimise their magnetic influence. In case of electric mains replace the key by a knife switch to avoid sparking. Adjust the rheostat so that a current of 8 to 10 amperes as recorded by the ammeter is obtained in the circuit.

Place the short magnetic needle at any point on the board near the vertical conductor. When the needle becomes steady, mark its two ends, by pencil dots. Now shift the position of the needle so that the dot, which was marked against the north pole, *just touches*

the south pole of the needle. Again put new dot against its north pole. In this way by continuously shifting the position of the needle, obtain a number of points round the wire. Join all these points by a free hand curve, and get a complete line of force round the conductor. The dots should be *very* accurately marked or else the line of force so drawn may not show a closed curve. Then increase the distance of the needle from the conductor slightly and in a similar way trace another line of force. In this way plot a few lines of force around the vertical wire along a horizontal plane (Fig. 296).

It would be noticed that from some distance of the conductor lines of force cease to be closed curves. These are due to earth's magnetic field playing a more prominent part than the field due to the conductor. A small region is actually obtained, which is bounded on opposite sides by reverse fields and the small magnetic needle being placed at this region shows little tendency to point any direction. This is actually the neutral point where earth's horizontal intensity is equal and opposite to the intensity of the field due to the linear conductor. The distance of the midpoint of this region from the axis of the conductor is measured.

Change the value of the current in the conductor by the rheostat and draw fresh lines of force on another paper.

Result—

The current in the circuit =

The distance of the neutral point from the centre of the hole =

$$\therefore \quad H = \frac{\cdot 2C}{d} =$$

Discussions—The current through the linear conductor should be very large or else the neutral point should be very near the conductor. The shorter is the tracing magnetic needle, the finer are curves traced out.

ORAL QUESTIONS

Do you know of any law giving the magnetic field due to a linear current? What is that law? What is the nature of the field due to the current alone? Is it modified due to earth's magnetic field? Why is the neutral point formed?

Date—

EXPERIMENT 158

To determine the Variation of the Magnetic Field along the axis of a Circular coil

Theory—The intensity F at a distance x from the centre of a circular coil along its axis is given by the expression,

$$F = \frac{2\pi n a^2 C}{(a^2+x^2)^{\frac{3}{2}}}$$

where n = number of turns in the coil
a = radius of the coil
C = current in electromagnetic unit

If this intensity is made to act on a freely suspended magnetic needle at right angles to the magnetic meridian producing a deflection, then

$$F = H \tan\theta = \frac{2\pi n a^2 C}{(a^2+x^2)^{\frac{3}{2}}}$$

$$\text{or,}\quad (a^2+x^2)^{\frac{3}{2}} \tan\theta = \frac{2\pi n a^2 C}{H}$$

At any locality H is constant; for a given coil and current na^2 and C are constants. And so the right side expression is constant.

Hence $(a^2+x^2)^{\frac{3}{2}} \tan\theta = \text{constant}$.

Apparatus—A coil of wire wound on a circular wooden frame, a deflection magnetometer with arms capable to sliding through the coil, a battery, rheostat and key.

The apparatus consists of an ordinary magnetometer box M with its arms AB capable of sliding through two wooden uprights (Fig. 297). A coil C of wire is wound upon a vertical wooden ring which is placed at the centre of the frame. The magnetometer box can just slide through the ring and the height of the box is so adjusted that the magnetic needle is at the centre of the ring.

Procedure—Rotate the plane of the coil with its attachments along a vertical axis until the axis of the needle is parallel to the plane of the coil. The coil is then set in the magnetic meridian,

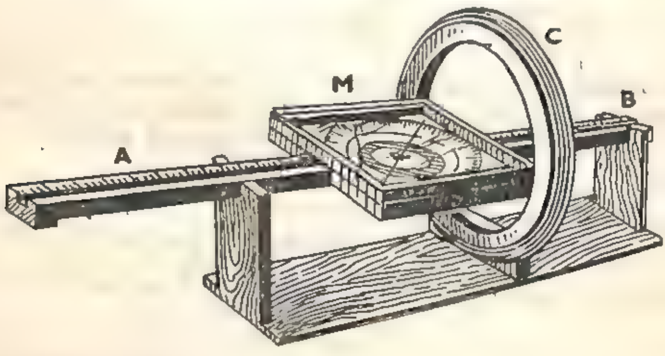


Fig. 297

To ensure a free movement of the needle, level the magnetometer box with a spirit level. The pointers of the needle usually read $0° - 0°$ of the circular graduated scale in this position. Connect the terminals of the coil C to the battery, through the rheostat and key.

Slide the magnetometer box through a distance of about 1 cm. at the centre of the coil; this can be ensured by placing eye just above the plane of the coil and sliding the arms of the magnetometer till the needle is obstructed by vision. Take care at every step not to disturb the position of the coil.

Now, send a current through the coil and note the deflections of the pointers. If deflection appears to be too small or too large adjust the rheostat to produce a deflection between 50° to 60°. Take the readings of both ends of the pointer for direct and reverse currents.

Slide the magnetometer box through a distance of about 1 cm. at right angles to the coil and note the deflection of the pointer. In this way by successively displacing the box through 1 cm. tabulate the deflections. Finally, plot a curve with the distance from the coil as abscissa and the corresponding deflection as ordinate.

Results—

No. of obs	Distance x	Deflection θ deg. mean	Square of radius a^2 sq. cm.	$(a^2+x^2)^{\frac{3}{2}}$	tan θ	$(a^2+x^2)^{\frac{3}{2}}$ ×tan θ
1	0	68°	100	1006	2·4751	24751
2	1	67°30′	,,	1015	2·4143	
3	2	66°30′	,,	1060·8	2·2998	
4	3	65°30′	,,	1138	2·1445	24804
5	4	63°30′	,,	1249	2·0057	
6	5	61°	,,	1397·5	1·8040	
7	9	57°	,,	1591	1·5108	24706

Number of turns in the coil = 50

Average radius of the coil = 10 cm.

Current through the coil = ·225 amp.

Discussions—The plane of the coil should be placed accurately in the magnetic meridian to ensure the constancy of the product. Deflections too large or too small, should not be recorded, as then a small error in measuring a deflection entails a large error in finding the tangent of the angle. Both sides of the pointers of the needle should be read.

ORAL QUESTIONS

Define a line of force. How can a line of force be traced by a magnetic needle? How does a magnetic field vary with distance along the axis of a circular coil? What is the nature of the field at the centre of the coil? Do you know of any practical application of utilising such a magnetic field at the centre of a coil of wire?

Date—

EXPERIMENT 159

To Find the Figure of Merit of the given Mirror Galvanometer

Theory—The figure of merit of a galvanometer is the amount of current through it to deflect the spot of light through a distance of one milimetre on a scale placed at a distance of one metre from the mirror of the galvanometer.

If a cell of e.m.f. E volts having a series resistance R ohms sends a current of C_g ampere through a galvanometer of resistance G ohms provided with a shunt of S ohms, producing a deflection of d mm. on a scale placed at a distance of D cm. then,

$$C_g = \frac{ES}{RS + RG + SG} = kd$$

where k is a constant. Had the scale been placed at a distance of 100 cm. then the deflection by the law of proportion would have been,

$$\frac{d \times 100}{D} \text{ mm.}$$

$$\text{Hence, } C_g = \frac{ES}{RS + RG + SG} = K\frac{d \times 100}{D} = KN, \text{ say, whence}$$

$$K = \text{figure of merit} = \frac{C_g}{N} \text{ amp/mm.}$$

Apparatus—A suspended coil galvanometer, a storage coil, two resistance boxes, a commutator and some connecting wires.

Procedure—Connect a resistance box S in parallel with the galvanometer. as shown in fig. 298. Join the terminals of a cell E to the two points of a commutator K. Connect two other terminals of the commutator to the galvanometer through a resistance R in series.

Put all the plugs tightly in the shunt S so that the shunt has zero resistance. Insert a resistance of 2000 to 3000 ohms in the series resistance R and close the commutator circuit. The galvanometer shows no deflection. This means that all the current is passing through the shunt and nothing through the galvanometer. Then beginning from the lowest resistance, go on increasing the shunt resistance and observe the deflection of the spot of light. You would see that with shunt resistance increasing, the deflection also increases. Choose the resistance from the shunt for which the spot of light is deflected through 5 to 10 cm. on the scale This choice of resistance, you have to make by trial. Then record the values of series and shunt resistances. Now reverse the current and note the deflection in the opposite direction.

Fig. 298

Take a series of readings each time changing the series and the shunt resistances but deflections varying from 5 to 10 cm. and tabulate the results. Finally, measure the perpendicular distance between the scale and the mirror of the galvanometer with a metre scale.

Results—

No. of obs.	Series resistance ohms.	Shunt resistance ohms.	Deflections direct mm.	Deflections reversed mm.	Deflections Mean mm.	N. in mm.	C_g	Figure of merit
1	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...
...								
5	...	...	...	...	...	...	...	...

The distance of the scale from the mirror = (i) ... (ii)
mean distance =
The resistance of the galvanometer = ... (supplied)
Thus the mean value of the figure of merit = ... amp/mm.

Discussions—The figure of merit of a galvanometer is an indication of its sensitivity to a current. Hence the coil of a highly current sensitive galvanometer should have a large number of turns of parferably thin wire. Hence the resistance of the galvanometer coil is considerable. The deflection of the galvanometer should not be more than 10 cm. for a scale distance of 100 cm. as otherwise equal changes of current do not produce equal linear deflections. Before starting a new set of readings, the shunt should always be kept at a zero value and the shunt resistance carefully handled to get a regular deflection.

Oral Questions

What is the figure of merit of a galvanometer? Distinguish between a galvanometer, an ammeter and a voltmeter. What is the distinction between a current sensitive and a voltage sensitive galvanometer? Which type of a galvanometer you expect to have a high value of the figure of merit and why?

Date—

Experiment 160

To Set up the installation of an Electric Bell with a Push button switch

Apparatus—Electric bell, push button switch, dry cell or Lechlanche's cell and some connecting wires.

An electric bell consists of a horse-shoe electromagnet carrying two coils L and M of insulated copper wire wound in opposite directions and are connected in series (Fig. 299). A soft iron armature *a*, held by a spring J in contact with a screw D, carries a hammer C resting against a bell G. One terminal of the coil is connected to the binding screw A and its other terminal to the spring J. The binding screw B is connected to the screw D.

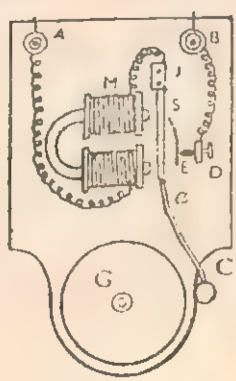


Fig. 299

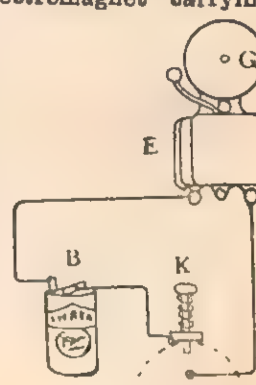


Fig. 300

Procedure—Connect any terminal of the cell to a binding screw of the electric bell and its other terminal to the binding screw of the push button switch. Finally connect the other binding screw of the bell to the remaining binding screw of the push-button switch. Adjust the contact screw till it just touches the armature of the electromagnet (Fig. 300).

On pressing the button K of the switch, an electrical contact is established in it and circuit is thereby complete. The current from the cell circulates the coils of the electromagnet which is magnetised. The soft iron armature is attracted and the hammer attached to it, strikes the bell.

But when the armature is attracted, the screw D is detached from it and the circuit is thereby broken. The current stops and the electromagnet being demagnetised, ceases to attract the armature. The spring brings back the armature to touch the screw point and the circuit is again complete. Thus the operation is repeated and the bell keeps on ringing.

If it is desired to run two or more electric bells with a single switch, connect all the bells in *parallel*. In this case the current taken from the cell would be in proportion to the number of bells used, and consequently instead of one cell, two or three cells may conveniently be connected in *parallel*.

If an electric bell is to be run from the D. C. mains, a proper resistance is to be inserted in series with the bell. But in case of A. C. mains, it must be converted to D. C. before being applied to the bell circuit. This can be done most conveniently by metal rectifiers.

When it is desired to run a number of electric bells, each one by a separate switch, the bells are to be connected in the same manner as lamps in the mains.

APPENDIX I

Sources of Errors in an Experiment

Various kinds of errors are involved in physical measurements. But broadly speaking there are two main types of errors—*systematic* and *random*.

Systematic Errors—These include all inaccuracies that tend to be more on one side of the ideal value. Examples of such errors are : (a) errors due to method of procedure (b) errors due to environment (c) personal errors (d) instrumental errors. The worker, after correcting instrumental error if any and with skill and experience may bring down such errors to an insignificant proportion.

Random Errors—Even when systematic errors are reduced to a minimum, we are apt to stray away more or less from the ideal value when we take a large number of readings for any physical measurement according to the laws of probability. Large fluctuations are much less likely than small ones. These laws tell us that positive and negative fluctuations are equally probable.

Calculation of mean Errors—It has already been stated in the Introductory that in taking a reading in an Experiment, we are liable to make an error, called the Personal Error. In taking a number of readings for a fixed quantity, this error in some cases leads to slightly larger value and in some other cases to a slightly smaller value than the ideally correct result. We never get this ideal value, but if we take the arithmetic mean of a *large number* of independent and unbiased readings with a correct instrument, this mean value is *very near* the ideal value.

We first deal with a simple and approximate method of calculating probable error in a set of readings Suppose that in measuring the focal length of a concave mirror, we have got from 10 individual settings, 10 values of the focal length in cms. as given below.

14·9, 15·0. 14·8, 14·9, 15·1, 14·9, 15·0. 14·9, 14·8, 15·1.

The arithmetic mean of all these value is 14·94. The difference between the individual values and the mean is called the *residual* or *deviation*. Now find the deviations in the following way

Reading	Mean	Deviation	Reading	Mean	Deviation
14·9	14·94	−·04	14·9	14·94	−·04
15·0	14·94	+·06	15 0	14·94	+·06
14·8	14·94	−·14	14·9	14·94	−·04
14·9	14·94	−·04	14·8	14·94	−·14
15·1	14 94	+·16	15·1	14·94	+·16

Now add the deviations irrespective of their algebraic signs and divide the sum by the number of observation. This value gives ·09.

which is called the *mean error* of the mean value of the focal length of 14·94. Therefore the result may be stated as,

14·94 ± 09 cm.

This means that the true focal length may have any value between 15·03 cm, and 14·85 cm. The maximum error is evidently ·09 in a value of 14·94 cm. Hence the maximum percentage of error is 0·6%.

Calculation of Probable error from Method of Least Squares

When there is a *large* number of independent observations for a certain quantity, it may be possible to determine the mean error and the probable error of a set of observations, by applying the mathematical law of probability. Here only the mechanical method is to be given.

Let there be n observations or readings of a quantity denoted by $x_1, x_2, x_3 \ldots x_{n-1}, x_n$. First add all the numbers and divide the sum by n, which gives the mean value. Let the mean value be given by x. Then subtract the mean value from each reading to get deviations, $\delta_1, \delta_2, \delta_3 \ldots \delta_{n-1}, \delta_n$. Get the individual *squares* of the deviations and add all δ^2. Then the mean error or the standard deviation of the result is $\sqrt{\Sigma\delta^2/n(n-1)}$ and the probable error of the result is

$$e = \cdot 6745\sqrt{\frac{\Sigma\delta^2}{n(n-1)}} \text{ or approximately} = \frac{2}{3}\sqrt{\frac{\Sigma\delta^2}{n(n-1)}}$$

We are now calculating the probable error of the focal length by the method of least squares.

No. of readings	Observed f cms.	Mean $f = fm$	Deviation $\delta = f - fm$	Square of deviations δ^2	Sum of δ^2
1	14·9		−·04	00·6	
2	15·0		+·06	·0036	
3	14·8		−·14	·0196	
4	14·9		−·04	·0016	
5	15·1		+·16	·0256	
6	14·9	14·94	−·04	·0016	·1040
7	15·0		+·06	·0036	
8	14·9		−·04	·0016	
9	14·8		−·14	·0196	
10	15·1		+·16	·0256	

The mean error of the result $= \sqrt{\frac{\cdot 1040}{10 \times 9}} = \sqrt{11 \cdot 6 \times 10^{-4}} = \cdot 034$

The probable error is $\frac{2}{3} \times \cdot 034 = \cdot 023$ cm.

The focal length of the mirror can then be expressed as 14·94 ± 023 cm.

APPENDIX II

Significant Figures.—In physical calculations, we get sometimes very large or very small arithmetical numbers. Take for example a number 1930 000 000,000 which represents the value of Young's modulus for mild steel in C.G.S units or a quantity ·00005896 which represents the wave length of sodium flame in centimetre. The zeroes of these two numbers express how big or small these numbers are in powers of ten. But 193 and 5896 are the significant figures of such numbers. Thus the first number is 193×10^{10} and the second one is 5896×10^{-8}. The significant figures express the accuracy with which a physical quantity may be expressed.

Suppose that in an experiment to determine Young's modulus, the estimation of percentage error gives a value of $\pm 1\%$, and the mean significant figure is 193. To be within $\pm 1\%$ of 193, the variation of the number is from 195 to 191, that is 193 ± 2. Thus we can express the values as $(193 \pm 2) \times 10^{10}$ or, $(19{\cdot}3 \pm {\cdot}2) \times 10^{11}$. It is usual to express the uncertain figure as a decimal and certain figure as integral, and finally to express the value in powers of ten.

LOGARITHMIC CALCULATIONS

Logarithms

In making calculations with quantities involved in an experiment, it becomes sometimes less troublesome to use logarithmic charts. In dealing with a quantity having a fractional power, the use of the logarithmic table is almost indispensable. Hence it will not be out of place at this stage to mention the fundamental principles of logarithm and method of using a log-table in making calculations. Recently electronic Desk Calculators have partially replaced Logarithmic Calculations.

Logarithm of a number with respect to a *given base is the index of the power* to which the base must be raised in order to be equal to the given number. Thus, if $a^y = b$, then y is the index of the power to which the base a is to be raised to be equal to b. Hence, by definition, y called the logarithm of b to the base a. It is generally written in the form

$$y = \log_a b$$

We can express the following arithmetical identities in terms of logarithms :—

Since $2^3 = 8$ $\quad\therefore\quad 3 = \log_2 8$

$3^4 = 81$ $\quad\therefore\quad 4 = \log_3 81$

$10^3 = 1000$ $\quad\therefore\quad 3 = \log_{10} 1000$, and so on

In general, if $a^x = \text{B}$ then $x = \log_a \text{B}$

$$\therefore \quad a^{\log_a \text{B}} = \text{B}$$

Properties of Logarithms

(1) We know that if a be any real finite quantity, then $a^0 = 1$. Hence $\log_a 1 = 0$ or logarithm of unity to any real finite base in zero.

For example, $\log_{10} 1 = 0$; $\log_e 1 = 0$, etc.

(2) We know that $a^1 = a$. Hence $\log_a a = 1$ or logarithm of any number with respect to the same number as the base is unity.

For example, $\log_{10} 10 = 1$; $\log_e e = 1$ etc.

(3) Logarithm of the product of two quantities to a base is equal to sum of their logarithms taken separately to the same base. In other words,

$$\log_a(m \times n) = \log_a m + \log_a n$$

To prove the identity, put $\log_a m = x$ and $\log_a n = y$

Then $a^x = m$ and $a^y = n$ $\quad\therefore\quad m \times n = a^{x+y} = a^z$, say.

$$\therefore \quad \log_a (m \times n) = z = x + y = \log_a m + \log_a n$$

Similarly, $\log_a(m \times n \times p \times \ldots) = \log_a m + \log_a n + \log_a p + \ldots$

For example,

$\log_{10}(3 \times 8{\cdot}2 \times {\cdot}4) = \log_{10} 3 + \log_{10} 8{\cdot}2 + \log_{10} {\cdot}4$

(4) Logarithm of the quotient of two numbers to a base is equal to the difference of their logarithms. In other words,

$$\log_a\left(\frac{m}{n}\right) = \log_a m - \log_a n$$

To prove the identity, put $\log_a m = x$ and $\log_a n = y$

Then $a^x = m$ and $a_y = n$ $\quad \therefore \quad \frac{m}{n} = \frac{a^x}{a_a} = a^{x-y} = a^z$, say.

$\therefore \quad \log_a\left(\frac{m}{n}\right) = z = x - y = \log_a m - \log_a n$

For example,
$\log_{10}\frac{5}{7} = \log_{10}5 - \log_{10}7$

(5) Logarithm of a power of a number to a base is the product of the power and the logarithm of the number to the same base. In other words,

$$\log_a m^n = n \log_a m$$

To prove the identity put $\log_a m = x$
Then $a^x = m$ and $(a^x)^n = m^n = a^{nx}$
$\therefore \quad \log_a m^n = nx = n \log_a m$

For example,

$\log_{10}2^3 = 3\log_{10}2$; $\log_{10}5^{\frac{2}{3}} = \frac{2}{3}\log_{10}5$, etc.

(6) Logarithm of a number to any base may be changed to the logarithm of the *same number* to any other base in the following way,

$$\log_a m = \log_b m \times \log_a b$$

To prove this, put $\log_b m = x$ and $\log_a b = y$
Then $b^x = m$ and $a^y = b$ or $a^{xy} = m$
$\therefore \quad \log_a m = x \times y = \log_b m \times \log_a b$.
For example,

$$\log_{10} m = \log_e m \times \log_{10} e$$

(7) The product of two logarithms in which the number and the base are interchanged is equal to unity. In other words,

$$\log_a b \times \log_b a = 1$$

Let $\log_a b = x$, then $a^x = b$ or $a = b^{\frac{1}{x}}$

Then $\log_b a = \frac{1}{x} = \frac{1}{\log_a b} \quad \therefore \quad \log_b a \times \log_a b = 1$

Common and Napierian Logarithms

Since any number can be used as the base of the logarithms, there are innumerable ways of expressing any particular number in terms of logarithms. For example

Since $2^2 = 4$, $3^2 = 9$, $4^2 = 16$, $5^2 = 25$ $6^2 = 36$ etc.
$\therefore \quad 2 = \log_2 4 = \log_3 9 = \log_4 16 = \log_5 25 = \log_6 36$, etc.

In practice only two systems of logarithms are prevalent, *viz.*, Common system and Napierian system. For ordinary numerical calculations numbers are expressed in terms of logarithms to the base 10, first introduced by Henry Briggs. This is called the *Common Logarithm*. For example, $\log_{10}2$, $\log_{10}15$, etc., are common logarithms.

Certain series known as the exponential series is written as e which is an incommensurable number. By taking a required number

of terms of the series, the value of e may be calculated to any desired place of decimals. The value of e correct to 5 places of decimals is 2·71828. When numbers are expressed in terms of logarithms to the base e, they are called *Napierian Logarithms* after the name of Napier. For example, $\log_e 15$ etc., are Napierian logarithms.

To convert one system to the other, the following rule according to the property no. 6 is to be observed.

For instance, $\log_{10} 15 = \log_e 15 \times \log_{10} e = \log_e 15 \times \log_{10} 2{\cdot}7183$.

Now $\log_{10} 2{\cdot}7183 = {\cdot}4342 \quad \therefore \quad \log_e 15 \times {\cdot}4342 = \log_{10} 15$.

Characteristic and Mantissa

We may state a general expression for a common logarithm in the form $x = \log_{10} n$ or $10^x = n$, in which n might have any positive value, integral or fractional. Then x may be of any value positive or negative, integral or fractional.

For instance, let

(i) $n = 1000$, then $\log_{10} 1000 = 3$, ($x = 3$, a positive integer).

(ii) $n = 240$ which is greater than 100 but less than 1000.

Now $\log_{10} 1000 = 3$ and $\log_{10} 100 = 2$

$\therefore$ $\log_{10} 240$ is > 2 but < 3, hence $\log_{10} 240 = 2 +$ a fraction.

(iii) $n = {\cdot}01 = 10^{-2} = -2$ ($x =$ a negative integer).

(iv) $n = {\cdot}0004$ which is greater than 10^{-4} but less than 10^{-3}

$\therefore$ $\log_{10} {\cdot}0004$ is > -4 but < -3, hence $\log_{10} {\cdot}0004 = -4 +$ a fraction.

Let $\log_{10} {\cdot}0004 = -4 + {\cdot}6021$ ($x =$ a negative integer + a fraction).

The integral part of the logarithm of a number is called the *characteristic* and the decimal part is called the *mantissa*. Thus taking $\log_{10} 240 = 2{\cdot}3802$, its characteristic is 2 and mantissa is ·3802.

Henceforth *for all common logarithms to the common base 10 would not be written for convenience.* If two numerical quantities have same integers arranged in the same order but differing only in the position of the decimal point, then for the logarithms of the two numbers, the mantissa part would be equal. It is only the difference in characteristics which makes the difference in the position of the decimal point. For instance,

$\log 1234 = \log 123{\cdot}4 + \log 10 = \log 12{\cdot}34 + \log 100 = \log 1{\cdot}234 + \log 1000$
$= \log {\cdot}1234 + \log 1000$, by property No. 3.

Hence if $\log 1234 = 3{\cdot}0913$; then $\log 123{\cdot}4 = \log 1234 - \log 10 = 3{\cdot}0913 - 1 = 2{\cdot}0913$, $\log 12{\cdot}34 = \log 1234 - \log 100 = 3{\cdot}0913 - 2 = 1{\cdot}0913$ etc.

Therefore of the number 1234 wherever might be the decimal point the mantissa is always ·0913. If the number begins with a decimal point, then the characteristic becomes negative. For example,

$$\log 1234 = \log {\cdot}1234 + \log 10^4 = \log {\cdot}01234 + \log 10^5 = \log {\cdot}001234 + \log 10^6.$$

Hence log ·1234 = log 1233 − log 10^4 = 3·0913 − 4 = −1 + ·0913 ; log ·01234 = log 1234 − log 10^5 = 3·0913 − 5 = −2 + ·0913 ; log ·001234 = log 1234 − log 10^6 = 3·0913 − 6 = −3 + ·0913 etc.

If the characteristic becomes negative, it is customary to represent it by the symbol *bar* upon it. Thus

$-1 + \cdot 0913 = \bar{1}\cdot 0913$; $-3 + \cdot 0913 = \bar{3}\cdot 0913$ etc.

Method of choosing Characteristic

There are two principal features for the choice of the characteristic part of the logarithm of a number, *viz.*, numbers greater than unity and numbers less than unity.

(i) *Numbers greater than unity*—Consider the values of the following logarithms

log 1 = 0 ; log = 10 = 1 ; log 100 = 2 ; log 1000 = 3 ; log 10^4 = 4

It is clear from these identities that the logarithm of a number—

(a) between 1 and 10 lies between 0 and 1. That is the logarithm of a number containing 1 digit as its integral part is 0 + a positive fraction. Hence its characteristic is 0

(b) between 10 and 100 lies between 1 and 2. That is the logarithm of a number containing 2 digits as its integral part is 1 + a positive fraction. Hence its characteristic is 1.

(c) between 100 and 1000 lies between 2 and 3. That is the logarithm of a number containing three digits as its integral part is 2 + a positive fraction. Hence its characteristic is 2.

In a similar way it can be proved that the logarithm of a number containing n digits as its integral part will have its characteristic $(n-1)$.

(ii) *Number less than unity*—Consider again the values of the following logarithms.

log 1 = 0 ; log ·1 = −1 = $\bar{1}$; log ·01 = −2 = $\bar{2}$; log ·001 = −3 = $\bar{3}$ etc.

It is clear from these identities that the logarithm of a number

(a) between ·1 and 1 lies between $\bar{1}$ and 0. That is the logarithm of a number having no zero just after the decimal point is $\bar{1}$ + a positive fraction. Hence its characteristic is $\bar{1}$

(b) between ·01 and ·1 lies between $\bar{2}$ and $\bar{1}$. That is the logarithm of a number having *one zero* after decimal point is $\bar{2}$ + a positive fraction. Hence its characteristic is $\bar{2}$

(c) between ·001 and ·01 lies between $\bar{3}$ and $\bar{2}$. That is the logarithm of a number having *two zeroes* after decimal point is $\bar{3}$ + a positive fraction. Hence its characteristic is $\bar{3}$.

In a similar way it can be proved that if there are n zeroes decimal point, the characteristic is $\overline{n+1}$.

Finding mantissa from Log-Table

The mantissa for the logarithms of all numbers which have the same significant digits arranged in the same order are the same. Hence the position of decimal point does not affect the mantissa of the logarithm of a number. For instance, numbers 2345, 234·5, 23·45 2·345 have the same mantissa.

The logarithms to the base 10 of all integers from 0 to 200,000 have been evaluated. In ordinary four figure logarithmic charts, as

given on 430 – 31 the mantissa of the logarithms from 0 to 9999 have been supplied and the characteristics are to be put down by inspection.

The first vertical column supplies the first two digits. The next series of columns from 0 to 9 supply the third digit whatever it might be. The second series of columns from 0 to 9 gives the fourth digit. The value corresponding to all the given four digits supplies the value of its logarithm. Suppose that we want to find log 3456 from the log chart The first two digits are 34 and from the first vertical out of which we shall pick out that one which is in column No 5 of the first series corresponding to 5 as the third of the number 3456. The number in this column reads 5378. For the fourth digit 6 of the number, look to the second series 0 to 9 and find the value corresponding to 6 on this line. It is found to be 8, which is to be added to 5378 to get 5386. Then 5386 is the mantissa of log 3456. Since the number consists of 4 digits, the characteristic is 3. Hence finally, log 3456 = 3·5386.

Anti-Logarithm

The number equal to the value of a logarithm is called its *anti-logarithm*. Thus if log 24·65 = 1·3918, then anti-log 1·3918 = 24·65. Transformation of ordinary numbers into logarithm to the base 10 is the function of the log-chart, while the reverse transformation of logarithmic quantities to ordinary numbers is done by antilogarithm chart. As we have also the integral and decimal parts of an anti-log number.

To use Antilog Table

The decimal part of an anti-logarithmic number is only to be found from the table given on pp. 432-33. The integral part of the number determines the position of the decimal point. Finding a number from this table is similar to that of the log-table. For example, to find antilog 2·140, see from the antilog table the number corresponding to ·140 which is found to be 1380. Now exercise your judgment in the following way

anti-log $2 = 10^2 = 100$: anti-log $3 = 10^3 = 1000$

∴ anti-log 3·140 would be a number lying between 100 and 1000, but the digits that we have got are 1380. Hence unless we put the decimal point after *three digits* i.e., 138·0, the number can not be greater than 100 but less than 1000

∴ anti log 2·140 = 138·0

It is clear that in case of an integer n in an anti-log number the decimal point is to be placed in its value after $(n+1)$ digits.

Again, take the case of anti-log $\bar{3}$·921. Find the value of ·921 from anti-log table which is 8318.

Now anti-log $\bar{2} = 10^{-2}$ = ·01 and anti-log $\bar{3} = 10^{-3}$ = ·001

anti-log $\bar{3}$·921 lies between anti-log $\bar{3}$ and anti-log $\bar{2}$, remembering that $\bar{3}$·921 = −3 + ·921 = −2·079.

Hence, for the digits 8318 to lie between ·01 and ·001, it must be written as 008318

∴ anti-log $\bar{3}$·921 = ·008318.

In a similar way we see if there is an integer, n in anti-log number, there would be $(n-1)$ zeroes before it after the decimal point.

Illustrative examples

To avoid confusion, the following examples have been worked out to illustrate various ways of using log and anti-log tables given at the end of this chapter.

(1) Evalute, $32{\cdot}42 \times 1{\cdot}414 \times {\cdot}0048 \times 104{\cdot}8$

From log-table,

$\log 32{\cdot}42 = 1{\cdot}5108$
$\log 1{\cdot}414 = 0{\cdot}1404$
$\log {\cdot}0048 = \bar{3}{\cdot}6812$
$\log 104{\cdot}8 = 2{\cdot}0204$
By addition $1{\cdot}3628$

From anti-log table,
${\cdot}3628 = 2305$
so, anti-log $1{\cdot}3628 = 23{\cdot}05$
Hence the reqd. product $= 23{\cdot}05$

(2) Evaluate, $\dfrac{3{\cdot}14 \times 1{\cdot}4^2 \times 16{\cdot}8}{114{\cdot}3 \times 62{\cdot}9}$

From log-table,
numerator
$\log 3{\cdot}14 = {\cdot}4969$
$\log 1{\cdot}4 = {\cdot}1461$
$\log 1{\cdot}4 = {\cdot}1461$
$\log 16{\cdot}8 = 1{\cdot}2253$
By addition $2{\cdot}0144$

denominator
$\log 114{\cdot}3 = 2{\cdot}0581$
$\log 62{\cdot}9 = 1{\cdot}7987$
By addition $3{\cdot}8568$

Hence by subtraction
$2{\cdot}0144$
$3{\cdot}8568$
$\bar{2}{\cdot}1576$

From anti-log table,
anti-log $\bar{2}{\cdot}1576 = {\cdot}01437$ = required value

(3) Evaluate, $\dfrac{1}{14{\cdot}3 \times {\cdot}84}$

From log-table
numerator
$\log 1 = 0$

denominator
$\log 14{\cdot}3 = 1{\cdot}1553$
$\log {\cdot}84 = \bar{1}{\cdot}9243$
By addition $1{\cdot}2496$

Hence by subtraction,
$0{\cdot}0000$
$1{\cdot}2496$
$\bar{2}{\cdot}7504$

From anti-log-table
anti-log $\bar{2}{\cdot}7504 = {\cdot}05675$ = required value

(4) Evaluate, (i) $\sqrt[5]{38{\cdot}2}$ (ii) $\sqrt[7]{5{\cdot}6^3}$ (iii) $\sqrt[3]{{\cdot}0024}$ (iv) ${\cdot}012^{-\frac{7}{13}}$

(i) $\log \sqrt[5]{38{\cdot}2} = \log 38{\cdot}2^{\frac{1}{5}} = \frac{1}{5} \log 38{\cdot}2$

$\log 38{\cdot}2 = 1{\cdot}5821 \quad \therefore \quad \frac{1}{5} \log 38{\cdot}2 = \dfrac{1{\cdot}5821}{5} = {\cdot}3164$

anti-log ${\cdot}3164 = 2{\cdot}071 \quad \therefore \quad \sqrt[5]{38{\cdot}2} = 2{\cdot}072$

(ii) $\log \sqrt[7]{5{\cdot}6^3} = \frac{3}{7} \log 5{\cdot}6 = \frac{3}{7} \times {\cdot}7482 = {\cdot}2138$

anti-log ${\cdot}2138 = 1{\cdot}636 \quad \therefore \quad \sqrt[7]{5{\cdot}6^3} = 1{\cdot}635$

*(iii) $\log \sqrt[3]{{\cdot}0024} = \frac{1}{3} \log {\cdot}0024 = \dfrac{\bar{3}{\cdot}3802}{3}$

Now $\bar{3}{\cdot}3802 = -3 + {\cdot}3802 = -2{\cdot}6198 \quad \therefore \quad \dfrac{-2{\cdot}6198}{3} = -{\cdot}8733$

Again $-{\cdot}8733 = -1 + {\cdot}1267 = \bar{1}{\cdot}1267$

Anti-log $\bar{1}{\cdot}1267 = {\cdot}1339 \quad \therefore \quad \sqrt[3]{{\cdot}0024} = {\cdot}1339$

*(iv) $\log {\cdot}012^{-\frac{7}{13}} = -\frac{7}{13} \log {\cdot}012 = -\frac{7}{13} \times \bar{2}{\cdot}0792$

Now $\bar{2}{\cdot}0792 = -1{\cdot}9208 \quad \therefore \quad -\frac{7}{13} \times (-1{\cdot}9208) = 1{\cdot}0343$

anti-log $1{\cdot}0343 = 10{\cdot}82 \quad \therefore \quad {\cdot}012^{-\frac{7}{13}} = 10{\cdot}82$

*During the process of multiplication and division, numbers with barred quantities should be transformed into ordinary negative numbers. Again these may be re-transformed into barred quantities.

NATURAL LOGARITHM

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170						5	9	13	17	21	26	30	34	38
						0212	0253	0294	0334	0374	4	8	12	16	20	24	28	32	36
11	0414	0453	0492	0531	0569						4	8	12	16	20	23	27	31	35
						0607	0645	0682	0719	0755	4	7	11	15	18	22	26	29	33
12	0792	0828	0864	0899	0934						3	7	11	14	18	21	25	28	32
						0969	1004	1038	1072	1106	3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271						3	6	10	13	16	19	23	26	29
						1303	1335	1367	1399	1430	3	7	10	13	16	19	22	25	29
14	1461	1492	1523	1553	1584						3	6	9	12	15	19	22	25	28
						1614	1644	1673	1703	1732	3	6	9	12	14	17	20	23	26
15	1761	1790	1818	1847	1875						3	6	9	11	14	17	20	23	26
						1903	1931	1959	1987	2014	3	6	8	11	14	17	19	22	25
16	2041	2068	2095	2122	2148						3	6	8	11	14	16	19	22	24
						2175	2201	2227	2253	2279	3	5	8	10	13	16	18	21	23
17	2304	2330	2355	2380	2405						3	5	8	10	13	15	18	20	23
						2430	2455	2480	2504	2529	3	5	8	10	12	15	17	20	22
18	2553	2577	2601	2625	2648						2	5	7	9	12	14	17	19	21
						2672	2695	2718	2742	2765	2	4	7	9	11	14	16	18	21
19	2788	2810	2833	2856	2878						2	4	7	9	11	13	16	18	20
						2900	2923	2945	2967	2989	2	4	6	8	11	13	15	17	19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	4	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	5	6	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	7	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	8	9	10
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	8	9
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	6	7	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	5	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8

NATURAL LOGARITHM

	0	1	2	3	4	5	6	7	8	9	123	456	789
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	123	345	678
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	123	345	678
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	122	345	677
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	122	345	667
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	122	345	667
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	122	345	567
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	122	345	567
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	122	345	567
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	112	344	567
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	112	344	567
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	112	344	566
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	112	344	566
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	112	334	566
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	112	334	556
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	112	334	556
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	112	334	556
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	112	334	556
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	112	334	556
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	112	334	456
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	112	234	456
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	112	234	456
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	112	234	455
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	112	234	455
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	112	234	455
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	112	234	455
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	112	233	455
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	112	233	455
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	112	233	445
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	112	233	445
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	112	233	445
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	112	233	445
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	112	233	445
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	112	233	445
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	112	233	445
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	112	233	445
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	112	233	445
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	112	233	445
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	011	223	344
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	011	223	344
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	011	223	344
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	011	223	344
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	011	223	344
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	011	223	344
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	011	223	344
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	011	223	344
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	011	223	344
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	011	223	344
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	011	223	344
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	011	223	344
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	011	223	334

ANTI-LOGARITHM

	0	1	2	3	4	5	6	7	8	9	123	456	789
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0 0 1	1 1 1	2 2 2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0 0 1	1 1 1	2 2 2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0 0 1	1 1 1	2 2 2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0 0 1	1 1 1	2 2 2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0 1 1	1 1 2	2 2 2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0 1 1	1 1 2	2 2 2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0 1 1	1 1 2	2 2 2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0 1 1	1 1 2	2 2 2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0 1 1	1 1 2	2 2 3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0 1 1	1 1 2	2 2 3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0 1 1	1 1 2	2 2 3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0 1 1	1 2 2	2 2 3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0 1 1	1 2 2	2 2 3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0 1 1	1 2 2	2 3 3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0 1 1	1 2 2	2 3 3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0 1 1	1 2 2	2 3 3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0 1 1	1 2 2	2 3 3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0 1 1	1 2 2	2 3 3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0 1 1	1 2 2	2 3 3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0 1 1	1 2 2	3 3 3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0 1 1	1 2 2	3 3 3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0 1 1	2 2 2	3 3 3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0 1 1	2 2 2	3 3 3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0 1 1	2 2 2	3 3 4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0 1 1	2 2 2	3 3 4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0 1 1	2 2 2	3 3 4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0 1 1	2 2 3	3 3 4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0 1 1	2 2 3	3 3 4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0 1 1	2 2 3	3 4 4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0 1 1	2 2 3	3 4 4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0 1 1	2 2 3	3 4 4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0 1 1	2 2 3	3 4 4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0 1 1	2 2 3	3 4 4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0 1 1	2 2 3	3 4 4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1 1 2	2 3 3	4 4 5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1 1 2	2 3 3	4 4 5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1 1 2	2 3 3	4 4 5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1 1 2	2 3 3	4 4 5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1 1 2	2 3 3	4 4 5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1 1 2	2 3 3	4 5 5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1 1 2	2 3 4	4 5 5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1 1 2	2 3 4	4 5 5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1 1 2	2 3 4	4 5 6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1 1 2	3 3 4	4 5 6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1 1 2	3 3 4	4 5 6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1 1 2	3 3 4	5 5 6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1 1 2	3 3 4	5 5 6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1 1 2	3 3 4	5 5 6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1 1 2	3 4 4	5 6 6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1 1 2	3 4 4	5 6 6

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

NATURAL SINES

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences.				
											1′	2′	3′	4′	5′
0°	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	3	6	9	12	15
3	·0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3	6	9	12	15
4	·0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3	6	9	12	14
5	·0872	0889	0906	0924	0941	0958	0976	0993	1011	1028	3	6	9	12	14
6	·1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	3	6	9	12	14
7	·1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3	6	9	12	14
8	·1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3	6	9	12	14
9	·1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3	6	9	12	14
10°	·1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3	6	9	11	14
11	·1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	3	6	9	11	14
12	·2079	2096	2113	2130	2147	2164	2181	2198	2215	2233	3	6	9	11	14
13	·2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3	6	8	11	14
14	·2419	2436	2453	2470	2487	2504	2521	2538	2554	2571	3	6	8	11	14
15	·2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3	6	8	11	14
16	·2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3	6	8	11	14
17	·2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3	6	8	11	14
18	·3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3	6	8	11	14
19	·3256	3272	3289	3305	3322	3338	3355	3371	3387	3404	3	5	8	11	14
20°	·3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3	5	8	11	14
21	·3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3	5	8	11	14
22	·3746	3762	3778	3795	3811	3827	3843	3859	3875	3891	3	5	8	11	14
23	·3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3	5	8	11	14
24	·4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3	5	8	11	13
25	·4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3	5	8	11	13
26	·4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3	5	8	10	13
27	·4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	3	5	8	10	13
28	·4695	4710	4726	4741	4756	4772	4787	4802	4818	4833	3	5	8	10	13
29	·4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3	5	8	10	13
30°	·5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3	5	8	10	13
31	·5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2	5	7	10	12
32	·5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	2	5	7	10	12
33	·5446	5461	5476	5490	5505	5519	5534	5548	5563	5577	2	5	7	10	12
34	·5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2	5	7	10	12
35	·5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2	5	7	9	12
36	·5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	2	5	7	9	12
37	·6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2	5	7	9	12
38	·6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	2	5	7	9	11
39	·6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	2	4	7	9	11
40°	·6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2	4	7	9	11
41	·6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2	4	7	9	11
42	·6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	2	4	6	9	11
43	·6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2	4	6	8	11
44	·6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2	4	6	8	10

NATURAL SINES

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences.				
											1′	2′	3′	4′	5′
45°	·7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	2	4	6	8	10
46	·7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	2	4	6	8	10
47	·7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2	4	6	8	10
48	·7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2	4	6	8	10
49	·7547	7559	7570	7581	7593	7604	7615	7627	7638	7649	2	4	6	8	9
50°	·7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2	4	6	7	9
51	·7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2	4	5	7	9
52	·7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2	4	5	7	9
53	·7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2	3	5	7	9
54	·8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	2	3	5	7	8
55	·8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2	3	5	7	8
56	·8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	2	3	5	6	8
57	·8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2	3	5	6	8
58	·8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2	3	5	6	8
59	·8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1	3	4	6	7
60°	·8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1	3	4	6	7
61	·8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1	3	4	6	7
62	·8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1	3	4	5	7
63	·8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1	3	4	5	6
64	·8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1	3	4	5	6
65	·9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1	2	4	5	6
66	·9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1	2	3	5	6
67	·9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	1	2	3	4	6
68	·9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1	2	3	4	5
69	·9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1	2	3	4	5
70°	·9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1	2	3	4	5
71	·9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1	2	3	4	5
72	·9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1	2	3	3	4
73	·9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1	2	2	3	4
74	·9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1	2	2	3	4
75	·9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	1	1	2	3	4
76	·9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1	1	2	3	3
77	·9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1	1	2	3	3
78	·9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1	1	2	2	3
79	·9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1	1	2	2	3
80	·9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0	1	1	2	2
81	·9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0	1	1	2	2
82	·9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0	1	1	2	2
83	·9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0	1	1	1	2
84	·9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	0	1	1	1	2
85	·9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0	0	1	1	1
86	·9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0	0	1	1	1
87	·9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0	0	0	1	1
88	·9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0	0	0	0	0
89	·9998	9999	9999	9999	9999	1·000	1·000	1·000	1·000	1·000	0	0	0	0	0

NATURAL TANGENTS

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences.				
											1′	2′	3′	4′	5′
0°	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	3	6	9	12	15
3	·0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	3	6	9	12	15
4	·0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	3	6	9	12	15
5	·0875	0892	0910	0928	0945	0963	0981	0998	1016	1033	3	6	9	12	15
6	·1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	3	6	9	12	15
7	·1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	3	6	9	12	15
8	·1405	1423	1441	1459	1477	1495	1512	1530	1548	1566	3	6	9	12	15
9	·1584	1602	1620	1638	1655	1673	1691	1709	1727	1745	3	6	9	12	15
10°	·1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	3	6	9	12	15
11	·1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	3	6	9	12	15
12	·2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	3	6	9	12	15
13	·2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	3	6	9	12	15
14	·2493	2512	2530	2549	2568	2586	2605	2623	2642	2661	3	6	9	12	16
15	·2679	2698	2717	2736	2754	2773	2792	2811	2830	2849	3	6	9	13	16
16	·2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	3	6	9	13	16
17	·3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	3	6	10	13	16
18	·3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	3	6	10	13	16
19	·3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	3	7	10	13	16
20°	·3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	3	7	10	13	17
21	·3839	3859	3879	3899	3919	3939	3959	3979	4000	4020	3	7	10	13	17
22	·4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	3	7	10	14	17
23	·4245	4265	4286	4307	4327	4348	4369	4390	4411	4431	3	7	10	14	17
24	·4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	4	7	11	14	18
25	·4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	4	7	11	14	18
26	·4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	4	7	11	15	18
27	·5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	4	7	11	15	18
28	·5317	5340	5362	5384	5407	5430	5452	5475	5498	5520	4	8	11	15	19
29	·5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	4	8	12	15	19
30°	·5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	4	8	12	16	20
31	·6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	4	8	12	16	20
32	·6249	6273	6297	6322	6346	6371	6395	6420	6445	6469	4	8	12	16	20
33	·6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	4	8	13	17	21
34	·6745	6771	6796	6822	6847	6873	6899	6924	6950	6976	4	9	13	17	21
35	·7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	4	9	13	18	22
36	·7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	5	9	14	18	23
37	·7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	5	9	14	18	23
38	·7813	7841	7869	7898	7926	7954	7983	8012	8040	8069	5	9	14	19	24
39	·8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	5	10	15	20	24
40°	·8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	5	10	15	20	25
41	·8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	5	10	16	21	26
42	·9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	5	11	16	21	27
43	·9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	6	11	17	22	28
44	·9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	6	11	17	23	29

NATURAL TANGENTS

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences. 1′	2′	3′	4′	5′
45°	1·0000	0035	0070	0105	0141	**0176**	0212	0247	0283	0319	6	12	18	24	30
46	1·0355	0392	0428	0464	0501	**0538**	0575	0612	0649	0686	6	12	18	25	31
47	1·0724	0761	0799	0837	0875	**0913**	0951	0990	1028	1067	6	13	19	25	32
48	1·1106	1145	1184	1224	1263	**1303**	1343	1383	1423	1463	7	13	20	27	33
49	1·1504	1544	1585	1626	1667	**1708**	1750	1792	1833	1875	7	14	21	28	34
50°	1·1918	1960	2002	2045	2088	**2131**	2174	2218	2261	2305	7	14	22	29	36
51	1·2349	2393	2437	2482	2527	**2572**	2617	2662	2708	2753	8	15	23	30	38
52	1·2799	2846	2892	2938	2985	**3032**	3079	3127	3175	3222	8	16	24	31	39
53	1·3270	3319	3367	3416	3465	**3514**	3564	3613	3663	3713	8	16	25	33	41
54	1·3764	3814	3865	3916	3968	**4019**	4071	4124	4176	4229	9	17	26	34	43
55	1·4281	4335	4388	4442	4496	**4550**	4605	4659	4715	4770	9	18	27	36	45
56	1·4826	4882	4938	4994	5051	**5108**	5166	5224	5282	5340	10	19	29	38	48
57	1·5399	5458	5517	5577	5637	**5697**	5757	5818	5880	5941	10	20	30	40	50
58	1·6003	6066	6128	6191	6255	**6319**	6383	6447	6512	6577	11	21	32	43	53
59	1·6643	6709	6775	6842	6909	**6977**	7045	7113	7182	7251	11	23	34	45	56
60°	1·7321	7391	7461	7532	7603	**7675**	7747	7820	7893	7966	12	24	36	48	60
61	1·8040	8115	8190	8265	8341	**8418**	8495	8572	8650	8728	13	26	38	51	64
62	1·8807	8887	8967	9047	9128	**9210**	9292	9375	9458	9542	14	27	41	55	68
63	1·9626	9711	9797	9883	9970	**0057**	0145	0233	0323	0413	15	29	44	58	73
64	2·0503	0594	0686	0778	0872	**0965**	1060	1155	1251	1348	16	31	47	63	78
65	2·1445	1543	1642	1742	1842	**1943**	2045	2148	2251	2355	17	34	51	68	85
66	2·2460	2566	2673	2781	2889	**2998**	3109	3220	3332	3445	18	37	55	73	92
67	2·3559	3673	3789	3906	4023	**4142**	4262	4383	4504	4627	20	40	60	79	99
68	2·4751	4876	5002	5129	5257	**5386**	5517	5649	5782	5916	22	43	65	87	108
69	2·6051	6187	6325	6464	6605	**6746**	6889	7034	7179	7326	24	47	71	95	119
70°	2·7475	7625	7776	7929	8083	**8239**	8397	8556	8716	8878	26	52	78	104	131
71	2·9042	9208	9375	9544	9714	**9887**	0061	0237	0415	0595	29	58	87	116	145
72	3·0777	0961	1146	1334	1524	**1716**	1910	2106	2305	2506	32	64	96	129	161
73	3·2709	2914	3122	3332	3544	**3759**	3977	4197	4420	4646	36	72	108	144	180
74	3·4874	5105	5339	5576	5816	**6059**	6305	6554	6806	7062	41	81	122	163	204
75	3·7321	7583	7848	8118	8391	**8667**	8947	9232	9520	9812	46	93	139	186	232
76	4·0108	0408	0713	1022	1335	**1653**	1976	2303	2635	2972					
77	4·3315	3662	4015	4374	4737	**5107**	5483	5864	6252	6646					
78	4·7046	7453	7867	8288	8716	**9152**	9594	0045	0504	0970					
79	5·1446	1929	2422	2924	3435	**3955**	4486	5026	5578	6140					
80°	5·6713	7297	7894	8502	9124	**9758**	0405	1066	1742	2432					
81	6·3138	3859	4596	5350	6122	**6912**	7720	8548	9395	0264					
82	7·1154	2066	3002	3962	4947	**5958**	6996	8062	9158	0285					
83	8·1443	2636	3863	5126	6427	**7769**	9152	0579	2052	3572					
84	9·514	9·677	9·845	10·02	10·20	**10·39**	10·58	10·78	10·99	11·20					
85	11·43	11·66	11·91	12·16	12·43	**12·71**	13·00	13·30	13·62	13·95					
86	14·30	14·67	15·06	15·46	15·89	**16·35**	16·83	17·34	17·89	18·46					
87	19·08	19·74	20·45	21·20	22·02	**22·90**	23·86	24·90	26·03	27·27					
88	28·64	30·14	31·82	33·69	35·80	**38·19**	40·92	44·07	47·74	52·08					
89	57·29	63·66	71·62	81·85	95·49	**114·6**	143·2	191·0	286·5	573·0					

Mean differences no longer sufficiently accurate.

RECIPROCAL OF NUMBERS

	0	1	2	3	4	5	6	7	8	9	Subtract Differences. 1	2	3	4	5	6	7	8	9
10	1000	9901	9804	9709	9615	9524	9434	9346	9259	9174									
11	9091	9009	8929	8850	8772	8696	8621	8547	8475	8403	Mean differences not sufficiently accurate.								
12	8333	8264	8197	8130	8065	8000	7937	7874	7813	7752									
13	7692	7634	7576	7519	7463	7407	7353	7299	7246	7194									
14	7143	7092	7042	6993	6944	6897	6849	6803	6757	6711									
15	6667	6623	6579	6536	6494	6452	6410	6369	6329	6289	4	8	13	17	21	25	29	33	38
16	6250	6211	6173	6135	6098	6061	6024	5988	5952	5917	4	7	11	15	18	22	26	29	33
17	5882	5848	5814	5780	5747	5714	5682	5650	5618	5587	3	6	10	13	16	20	23	26	29
18	5556	5525	5495	5464	5435	5405	5376	5348	5319	5291	3	6	9	12	15	17	20	23	26
19	5263	5236	5208	5181	5155	5128	5102	5076	5051	5025	3	5	8	11	13	16	18	21	24
20	5000	4975	4950	4926	4902	4878	4854	4831	4808	4785	2	5	7	10	12	14	17	19	21
21	4762	4739	4717	4695	4673	4651	4630	4608	4587	4566	2	4	7	9	11	13	15	17	19
22	4545	4525	4505	4484	4464	4444	4425	4405	4386	4367	2	4	6	8	10	12	14	16	18
23	4348	4329	4310	4292	4274	4255	4237	4219	4202	4184	2	4	5	7	9	11	13	14	16
24	4167	4149	4132	4115	4098	4082	4065	4049	4032	4016	2	3	5	7	8	10	12	13	15
25	4000	3984	3968	3953	3937	3922	3906	3891	3876	3861	2	3	5	6	8	9	11	12	14
26	3846	3831	3817	3802	3788	3774	3759	3745	3731	3717	1	3	4	6	7	8	10	11	13
27	3704	3690	3676	3663	3650	3636	3623	3610	3597	3584	1	3	4	5	7	8	9	11	12
28	3571	3559	3546	3534	3521	3509	3497	3484	3472	3460	1	2	4	5	6	7	9	10	11
29	3448	3436	3425	3413	3401	3390	3378	3367	3356	3344	1	2	3	5	6	7	8	9	10
30	3333	3322	3311	3300	3289	3279	3268	3257	3247	3236	1	2	3	4	5	6	7	9	10
31	3226	3215	3205	3195	3185	3175	3165	3155	3145	3135	1	2	3	4	5	6	7	8	9
32	3125	3115	3106	3096	3086	3077	3067	3058	3049	3040	1	2	3	4	5	6	7	8	9
33	3030	3021	3012	3003	2994	2985	2976	2967	2959	2950	1	2	3	4	4	5	6	7	8
34	2941	2933	2924	2915	2907	2899	2890	2882	2874	2865	1	2	3	3	4	5	6	7	8
35	2857	2849	2841	2833	2825	2817	2809	2801	2793	2786	1	2	2	3	4	5	6	6	7
36	2778	2770	2762	2755	2747	2740	2732	2725	2717	2710	1	2	2	3	4	5	5	6	7
37	2703	2695	2688	2681	2674	2667	2660	2653	2646	2639	1	1	2	3	4	4	5	6	6
38	2632	2625	2618	2611	2604	2597	2591	2584	2577	2571	1	1	2	3	3	4	5	5	6
39	2564	2558	2551	2545	2538	2532	2525	2519	2513	2506	1	1	2	3	3	4	4	5	6
40	2500	2494	2488	2481	2475	2469	2463	2457	2451	2445	1	1	2	2	3	4	4	5	5
41	2439	2433	2427	2421	2415	2410	2404	2398	2392	2387	1	1	2	2	3	3	4	5	5
42	2381	2375	2370	2364	2358	2353	2347	2342	2336	2331	1	1	2	2	3	3	4	4	5
43	2326	2320	2315	2309	2304	2299	2294	2288	2283	2278	1	1	2	2	3	3	4	4	5
44	2273	2268	2262	2257	2252	2247	2242	2237	2232	2227	1	1	2	2	3	3	4	4	5
45	2222	2217	2212	2208	2203	2198	2193	2188	2183	2179	0	1	1	2	2	3	3	4	4
46	2174	2169	2165	2160	2155	2151	2146	2141	2137	2132	0	1	1	2	2	3	3	4	4
47	2128	2123	2119	2114	2110	2105	2101	2096	2092	2088	0	1	1	2	2	3	3	4	4
48	2083	2079	2075	2070	2066	2062	2058	2053	2049	2045	0	1	1	2	2	3	3	3	4
49	2041	2037	2033	2028	2024	2020	2016	2012	2008	2004	0	1	1	2	2	2	3	3	4
50	2000	1996	1992	1988	1984	1980	1976	1972	1969	1965	0	1	1	2	2	2	3	3	4
51	1961	1957	1953	1949	1946	1942	1938	1934	1931	1927	0	1	1	2	2	2	3	3	3
52	1923	1919	1916	1912	1908	1905	1901	1898	1894	1890	0	1	1	1	2	2	3	3	3
53	1887	1883	1880	1876	1873	1869	1866	1862	1859	1855	0	1	1	1	2	2	2	3	3
54	1852	1848	1845	1842	1838	1835	1832	1828	1825	1821	0	1	1	1	2	2	2	3	3
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
											Subtract Differences.								

RECIPROCAL OF NUMBERS

	0	1	2	3	4	5	6	7	8	9	Subtract Differences. 1	2	3	4	5	6	7	8	9
55	1818	1815	1812	1808	1805	1802	1799	1795	1792	1789	0	1	1	1	2	2	2	3	3
56	1786	1783	1779	1776	1773	1770	1767	1764	1761	1757	0	1	1	1	2	2	2	3	3
57	1754	1751	1748	1745	1742	1739	1736	1733	1730	1727	0	1	1	1	2	2	2	2	3
58	1724	1721	1718	1715	1712	1709	1706	1704	1701	1698	0	1	1	1	1	2	2	2	3
59	1695	1692	1689	1686	1684	1681	1678	1675	1672	1669	0	1	1	1	1	2	2	2	3
60	1667	1664	1661	1658	1656	1653	1650	1647	1645	1642	0	1	1	1	1	2	2	2	3
61	1639	1637	1634	1631	1629	1626	1623	1621	1618	1616	0	1	1	1	1	2	2	2	2
62	1613	1610	1608	1605	1603	1600	1597	1595	1592	1590	0	1	1	1	1	2	2	2	2
63	1587	1585	1582	1580	1577	1575	1572	1570	1567	1565	0	0	1	1	1	1	2	2	2
64	1563	1560	1558	1555	1553	1550	1548	1546	1543	1541	0	0	1	1	1	1	2	2	2
65	1538	1536	1534	1531	1529	1527	1524	1522	1520	1517	0	0	1	1	1	1	2	2	2
66	1515	1513	1511	1508	1506	1504	1502	1499	1497	1495	0	0	1	1	1	1	2	2	2
67	1493	1490	1488	1486	1484	1481	1479	1477	1475	1473	0	0	1	1	1	1	2	2	2
68	1471	1468	1466	1464	1462	1460	1458	1456	1453	1451	0	0	1	1	1	1	2	2	2
69	1449	1447	1445	1443	1441	1439	1437	1435	1433	1431	0	0	1	1	1	1	1	2	2
70	1429	1427	1425	1422	1420	1418	1416	1414	1412	1410	0	0	1	1	1	1	1	2	2
71	1408	1406	1404	1403	1401	1399	1397	1395	1393	1391	0	0	1	1	1	1	1	2	2
72	1389	1387	1385	1383	1381	1379	1377	1370	1374	1372	0	0	1	1	1	1	1	2	2
73	1370	1368	1366	1364	1362	1361	1359	1357	1355	1353	0	0	1	1	1	1	1	2	2
74	1351	1350	1348	1346	1344	1342	1340	1339	1337	1335	0	0	1	1	1	1	1	1	2
75	1333	1332	1330	1328	1326	1325	1323	1321	1319	1318	0	0	1	1	1	1	1	1	2
76	1316	1314	1312	1311	1309	1907	1305	1304	1302	1300	0	0	1	1	1	1	1	1	2
77	1299	1297	1295	1294	1292	1290	1289	1287	1285	1284	0	0	0	1	1	1	1	1	1
78	1282	1280	1279	1277	1276	1274	1272	1271	1269	1267	0	0	0	1	1	1	1	1	1
79	1266	1264	1263	1261	1259	1258	1256	1255	1253	1252	0	0	0	1	1	1	1	1	1
80	1250	1248	1247	1245	1244	1242	1241	1239	1238	1236	0	0	0	1	1	1	1	1	1
81	1235	1233	1232	1230	1229	1227	1225	1224	1222	1221	0	0	0	1	1	1	1	1	1
82	1220	1218	1217	1215	1214	1212	1211	1209	1208	1206	0	0	0	1	1	1	1	1	1
83	1205	1203	1202	1200	1199	1198	1196	1195	1193	1192	0	0	0	1	1	1	1	1	1
84	1190	1189	1188	1186	1185	1183	1182	1181	1179	1178	0	0	0	1	1	1	1	1	1
85	1176	1175	1174	1172	1171	1170	1168	1167	1166	1164	0	0	0	1	1	1	1	1	1
86	1163	1161	1160	1159	1157	1156	1155	1153	1152	1151	0	0	0	1	1	1	1	1	1
87	1149	1148	1147	1145	1144	1143	1142	1140	1139	1138	0	0	0	1	1	1	1	1	1
88	1136	1135	1134	1133	1131	1130	1129	1127	1126	1125	0	0	0	1	1	1	1	1	1
89	1124	1122	1121	1120	1119	1117	1116	1115	1114	1112	0	0	0	1	1	1	1	1	1
90	1111	1110	1109	1107	1106	1105	1104	1103	1101	1100	0	0	0	1	1	1	1	1	1
91	1099	1098	1096	1095	1094	1093	1092	1091	1089	1088	0	0	0	0	1	1	1	1	1
92	1087	1086	1085	1083	1082	1081	1080	1079	1078	1076	0	0	0	0	1	1	1	1	1
93	1075	1074	1073	1072	1071	1070	1068	1067	1066	1065	0	0	0	0	1	1	1	1	1
94	1064	1063	1062	1060	1059	1058	1057	1056	1055	1054	0	0	0	0	1	1	1	1	1
95	1053	1052	1050	1049	1048	1047	1046	1045	1044	1043	0	0	0	0	1	1	1	1	1
96	1042	1041	1040	1038	1037	1036	1035	1034	1033	1032	0	0	0	0	1	1	1	1	1
97	1031	1030	1029	1028	1027	1026	1025	1024	1022	1021	0	0	0	0	1	1	1	1	1
98	1020	1019	1018	1017	1016	1015	1014	1013	1012	1011	0	0	0	0	1	1	1	1	1
99	1010	1009	1008	1007	1006	1005	1004	1003	1002	1001	0	0	0	0	0	1	1	1	1
	0	1	2	3	4	5	6	7	8	9	1 Subtract Differences.	2	3	4	5	6	7	8	9

TABLES OF PHYSICAL CONSTANTS

1. Coefficients of Limiting Friction

Substances	Co-efficients	Substances	Co-efficients
Wood on wood	0·3 —0·5	Stone on stone	0·7
Metal on wood	0·1 —0·2	Metal on stone	0·55 - 0·65
Metal on metal	0·15—0·3	Metal on stone	0·5

2. Spcific Gravities of Common Substances

Substance	Sp. G.	Substance	Sp. Gr.	Substance	Sp. Gr.
Iron	7·7—7·9	Marble	2·5—2·8	Alum	1·70
Brass	8·4—8·7	Glass		Sugar	1·59
Gold	19·32	(Crown)	2·4—2·6	Cork	·22—·26
Copper	8·93	(Flint)	2·9 - 4·5	Glycerin	1·26
Silver	10·48	Sand	2·2—2·6	Turpentine	·87
Platinum	21·7	Paraffin Wax	·87—·96	Kerosene	·80
Lead	22·3	Sealing Wax	1·8	Castor oil	·97
Gun metal	8—8·4	Wood	·7—·9	Olive oil	·91—·93
Constantan	8·88	Wood, Ebony	1·1—1·2	Paraffin oil	·91—·93
Platinoid	9·0	Celluloid	1·4	Mustard oil	·8—·83

3. Young's Moduli of Common Metals

Substance	Young's Modulus dynes/cm²	Substance	Young's Modulus dynes/cm²
Copper	$1·1\times10^{12}$	Nickel	$2·1\times10^{12}$
Steel	$2·1\times10^{12}$	Silver	$0·7\times10^{12}$
Platinum	$1·7\times10^{12}$	Tungsten	$3·6\times10^{12}$
Brass	$0·9\times10^{12}$	German Silver	$1·1\times10^{12}$

4 Density of Water with Temperature

Temp °C	Density gm/c.c.	Temp. °C	Density gm/c.c.	Temp. °C	Density gm/c.c.
0	·99987	16	·99897	32	·99505
2	·99997	18	·99862	34	·99440
4	1·00000	20	·99828	36	·99371
6	·99997	22	·99780	38	·9930
8	·99988	24	·99732	40	·9922
10	·99973	26	·99691	42	·9915
12	·99953	28	·99626	44	·9907
14	·99927	30	·99567	46	·9898

5. Saturated Vapour Pressures of Water

Temp. °C	Press mm.	Temp. °C	Press mm.	Temp. °C	Press mm.
0	4·58	14	12·73	28	29·94
1	4·92	15	13·62	29	31·71
2	5·92	16	14·52	30	33·57
3	6·09	17	15·46	31	35·53
4	6·54	18	16·46	32	37·59
5	7·01	19	17·51	33	39·75
6	7·51	20	18·62	34	42·02
7	8·04	21	19·79	35	44·40
8	8·61	22	21·02	36	46·90
9	9·20	23	22·32	37	49·51
10	9·84	24	23·63	38	52·96
11	10·51	25	25·13	39	55·13
12	11·23	26	26·65	40	58·15
13	11·98	27	28·25	41	61·30

6. Specific Heat of Common Substances

Substances	Sp. Ht.	Substance	Sp. Ht.	Substances	Sp. Ht.
Brass	·088	Gold	·03	Mercury	·04
Copper	·094	Glass	·16	Ice	·5
Iron	·119	Marble	·22	Mustard oil	·39
Lead	·031	Turpentine	·50	Castor oil	·50
Silver	·055	Olive oil	·47	Bromine	·51

7. Dry and Wet Bulb Thermometers

Dry Bulb Temperature in °C	Glaisher's Factor	Dry Bulb Temperature in °C	Glaisher's Factor	Dry Bulb Temperature in °C	Glaisher's Factor
2	8·56	15	1·89	28	1·67
3	8·26	16	1·87	29	1·66
4	7·82	17	1·85	30	1·65
5	7·28	18	1·83	31	1·64
6	6·62	19	1·81	32	1·63
7	5·77	20	1·79	33	1·62
8	4·92	21	1·77	34	1·61
9	4·04	22	1·75	35	1·60
10	2·06	23	1·74	36	1·59
11	2·02	24	1·72	37	1·58
12	1·99	25	1·70	38	1·57
13	1·95	26	1·69	39	1·56
14	1·99	27	1·68	40	1·55

8. Boiling points of Water with Barometric Pressure

Barometric Pressure mm.	Boiling Point °C	Barometric Pressure mm.	Boiling Point °C	Barometric Pressure mm.	Boiling Point °C
740	99·25	752	99·70	764	100·15
742	99·33	754	99·78	766	100·22
744	99·41	756	99·85	768	100·29
746	99·48	758	99·93	770	100·37
748	99·56	760	100·00	772	100·44
750	99·63	762	100·07	774	100·51

9. Thermal Conductivities of Substances

Substance	Average temp. °C	Thermal conductivity C.G.S.	Substance	Thermal Conductivity C.G.S.
Aluminium	18	·49	Glass (crown)	$2·5 \times 10^{-3}$
Copper	18	·92	Glass (flint)	$2·0 \times 10^{-3}$
Gold	18	·70	Asbestos	$·6 \times 10^{-3}$
Iron (wrought)	18	·14	Fireclay	$·4 \times 10^{-3}$
Iron (cast)	50	·11	Ebonite	$·4 \times 10^{-3}$
Mercury	18	·02	Felt	$·09 \times 10^{-3}$
Nickel	18	·14	Flannel	$·23 \times 10^{-3}$
Silver	18	·97	Porcelain	$2·5 \times 10^{-3}$
Brass	17	·16	Rubber	$·45 \times 10^{-3}$

10. Specific Resistances of Metals

Substance	Sp. Resis. $\times 10^{-6}$	Temp. °C	Metal	Sp. Resis $\times 10^{-6}$	Temp. °C
Iron (cast)	16·8	100	German Silver	20—40	18
Iron (wrought)	13·9	18	Maganine	44·5	18
Platinum	11·0	18	Phosphor Bronze	5—10	18
Silver	1·66	18	Platinoid	34·4	18
Brass	6—9	18	Tungsten	6·0	25
Constantan	49	18			

11. Refractive Indices for Sodium Light

Substance	μ	Substance	μ	Substance	μ
Glass, Crown	1·48—1·56	Water	1·33	Cedar oil	1·51
Glass, Flint	1·58—1·96	Turpentine	1·47	Olive oil	1·44
Diamond	2·42	Glycerine	1·47	Paraffin oil	1·46

12. Terrestrial Magnetic Constants

Place	Year	Declination ° ′		Inclination ° ′		Horizontal Intensity C. G. S.	Vertical Intensity C. G. S.
North Magnetic Pole	...	...		90 0	N	...	...
South Magnetic Pole	1908	...		90 0	S	...	...
Aberdeen	1919	16 31	W	70 39	N	·163	·464
Greenwich	1919	14 18	W	66 54	N	·1840	·4325
Cape Town	1885	30 15	W	56 0	S	·199	·295
Agincourt	1916	6 33	W	74 44	N	·1599	·5854
Rio de Janim	1906	8 55	W	13 57	S	·2477	·0616
Bombay	1915	0 41	E	24 21	N	·3587	·1659
Calcutta	1914	0 22	E	30 59	W	·3740	·2246
Sydney	1885	9 30	E	62 30	S	·268	·515
Potsdam	1903	8 28	W	66 20	N	·1880	·4289

13 Electro-motive Forces of Cells and Internal Resistances

Cell	E.M.F.	Resistance ohm.	Cell	E M.F.	Resistance ohm.
Bichromate	2·0	—	Leclanche	1·5	·25—·4
Bunsen	1·8—1·9	—	Secondary	2·2 - 1·0	—
Daniell	1·08	·4	Weston	1·018	500
Grove	1·8—1·9	—	Clark	1·433	500

14. Coefficients of Linear expansion of solids

Substance	Coefficients $\times 10^{-6}$	Substances	Coefficients $\times 10^{-6}$
Aluminium	22	Iron	11·4
Brass	19	Platinum	9·0
Copper	17	Silver	20
Glass	8·3	Tin	23

15. Boiling Points of substances at normal pressure

Substance	Boiling Pt. °C	Substance	Boiling Pt. °C
Alcohol	78	Ether	35
Aniline	182	Glycerine	290
Chloroform	61	Mercury	357
Water	100	Turpentine	158

16. Coefficients of cubical expansion of liquid

Substance	Coefficients $\times 10^{-4}$	Substance	Coefficients $\times 10^{-4}$
Alcohol	11·2	Olive oil	7·0
Aniline	2·0	Sulphuric Acid	95
Glycerine	5·0	Turpentin	9·7
Mercury	1·8	Water	2·03

17. Critical Angles

Substance	Critical angle degree (average)	Substance	Critical angle degree
Crown glass	41°	Water	48°30′
Flint Glass	37°	Glycerine	44°30′
Diamond	24°	Paraffin	44°12′